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Report

Preparatory Studies for Product Group in the Ecodesign Working Plan 2012-2014:

Lot 8- Power Cables

Task 3 report – Users (product demand side) (3rd version)

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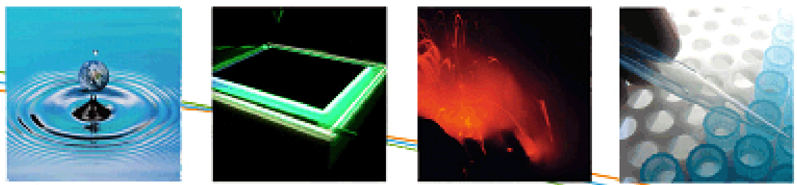

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EXECUTIVE SUMMARY

VITO is performing the preparatory study for the new upcoming ecodesign directive for Energy-related Products (ErP) related to power cables, on behalf of the European Commission (more info http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/index_en.htm).

In order to improve the efficient use of resources and reduce the environmental impacts of energy-related products the European Parliament and the Council have adopted Directive 2009/125/EC (recast of Directive 2005/32/EC) establishing a framework for the setting Ecodesign requirements (e.g. energy efficiency) for energy-related products in the residential, tertiary, and industrial sectors. It prevents disparate national legislations on the environmental performance of these products from becoming obstacles to the intra-EU trade and contributes to sustainable development by increasing energy efficiency and the level of protection of the environment, taking into account the whole life cycle cost. This should benefit both businesses and consumers, by enhancing product quality and environmental protection and by facilitating free movement of goods across the EU. It is also possible to introduce binding information requirements for components and sub-assemblies.

The MEErP methodology (Methodology for the Ecodesign of Energy-related Products) allows the evaluation of whether and to which extent various energy-using products fulfil the criteria established by the ErP Directive for which implementing measures might be considered. The MEErP model translates product specific information, covering all stages of the life of the product, into environmental impacts (more info http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/methodology/index_en.htm).

The tasks in the MEErP entail:
Task 1 - Scope (definitions, standards and legislation);
Task 2 – Markets (volumes and prices);
Task 3 – Users (product demand side);
Task 4 - Technologies (product supply side, includes both Best Available Technology (BAT) and Best Not Yet Available Technology (BNAT));
Task 5 – Environment & Economics (base case Life Cycle Assessment (LCA) & Life Cycle Costs (LCC));
Task 6 – Design options (improvement potential);
Task 7 – Scenarios (policy, scenario, impact and sensitivity analysis).
Tasks 1 to 4 can be performed in parallel, whereas 5, 6 and 7 are sequential.
Task 0 or a Quick-scan is optional to Task 1 for the case of large or inhomogeneous product groups, where it is recommended to carry out a first product screening. The objective is to re-group or narrow the product scope, as appropriate from an ecodesign point of view, for the subsequent analysis in tasks 2-7.

TABLE OF CONTENTS

Distribution List I

Executive Summary.. II

Table of Contents III

List of Figures IV

List of Tables...V

List of Acronyms VI

CHAPTER 3 Task 3: Users 10

3.1 Systems aspects of the use phase for ErPs with direct impact 11

3.1.1 Definition of the user and context ________________________________ 13

3.1.2 Loss parameters directly related to the cable itself____________________ 13

3.1.3 Other functional cable parameters not directly related to losses ________ 17

3.1.4 Loss parameters directly related to the electrical circuit and network topology 18

3.1.5 Parameters related to the building and loading________________________ 30

3.1.6 Formulas used for power losses in cables ____________________________ 37

3.2 Systems aspects of the use phase for ErPs with indirect impact 39

3.2.1 Building space heating and cooling system ___________________________ 39

3.3 End-of-Life behaviour 39

3.4 Local infrastructure (barriers and opportunities)...................................... 45

3.4.1 Opportunities____ 45

3.4.2 Barriers ____ 46

3.4.3 Installers and certifiers of electrical installations ____________________ 52

3.4.4 Physical environment ____ 52

Annex 3-A 53

LIST OF FIGURES

Figure 3-1: Three groups of ErP, distinguished by their impact (source: MEErP 2011 Methodology Part 1) 10
Figure 3-2: From strict product to systems approach 12
Figure 3-3: Simplified 1-wire diagram of an electric installation 12
Figure 3-4: Resistance increase due to skin effect at 50Hz for Cu and Al conductors .. 17
Figure 3-5: Voltage drop in an electrical installation 19
Figure 3-6: Example of a 'two wire installation' 20
Figure 3-7: Typical wiring diagram 22
Figure 3-8: Kd in function of load branch length factor and number of nodes 25
Figure 3-9: Some examples of method of installation (IEC 60364-5-52) 28
Figure 3-10: Different thermal conditions 29
Figure 3-11: Recycling flow of wires and cables[14]. 39
Figure 3-12: Schematic diagram of mechanical recycling process[14], see Figure 3-14 for more details. 40
Figure 3-13: Basic cable stripping machines[14]. 40
Figure 3-14: Detailed process flow of cable waste shredding[14]. 42
Figure 3-15: The Vinyloop® process. 43
Figure 3-16: Amounts of recycled PVC (in tonnes) within the Vinyl 2010's and VinylPlus' frameworks. 43

LIST OF TABLES

Table 3-1: Properties of Aluminium and Copper 14
Table 3-2: Minimum and maximum cable cross-sectional areas per circuit type........ 15
Table 3-3: Construction type versus maximum resistance (at 20° C) 18
Table 3-4: Average circuit length in meters according questionnaire[5] 21
Table 3-5: Kd factors for circuits with minimum 1 to maximum 8 socket-outlets with equally distributed loads and cable segment lengths 22
Table 3-6: Kd factors for circuits with up to 30 nodes in function of load branch length factor 24
Table 3-7: Average number of nodes per circuit application type according to questionnaire 26
Table 3-8: Kd factor per circuit type 27
Table 3-9: Diversity factor in function of the number of circuits according IEC 61439-3 30
Table 3-10: Load form factor and load factors in the residential sector 32
Table 3-11: Load form factor and load factors in the services sector 33
Table 3-12: Load form factor and load factors in the industry sector 34
Table 3-13: Load factors (α_c) and load form factors (Kf) to be used in this study 35
Table 3-14: Reduction factors for harmonic currents in four-core and five-core cables 37
Table 3-15: Comparison between mechanical and manual separation process[14]. 40
Table 3-16: Lifetime parameters per sector 44
Table 3-17: End of life parameters 45
Table 3-18: Lifetime of wiring according NAHB 48
Table 3-19: Lifetime of cables and wires according their application[21] 49
Table 3-20: Assumed working life of construction products 50
Table 3-21: Minimum design life of components 50
Table 3-22: Design working life of components 50
Table 3-23: Lifetime of cables and wires according their application 51
Table 3-24: Cable product lifetime 51
Table 3-25: Kd factors: load branch length factor equal to 10% 54
Table 3-26: Kd factors: load branch length factor equal to 50% 55
Table 3-27: Kd factors: load branch length factor equal to 100% 56
Table 3-28: Kd factors: load branch length factor equal to 200% 57

1 List of Acronyms

A	Amperage
α_c	Corrected or circuit load factor
AC	Alternating Current
Al	Aluminium
AREI	Algemeen Reglement op de Elektrische Installaties
Avg	Average
B2B	Business–to-business
BAT	Best Available Technology
BAU	Business As Usual
BNAT	Best Not yet Available Technology
CE	Conformite Europee
CEN	European Committee for Normalisation
CENELEC	European Committee for Electro technical Standardization
CPD	Construction Products Directive
CPR	Construction Products Regulation
CSA	conductor Cross-Sectional Area
Cu	Copper
DC	Direct Current
DIN	Deutsches Institut für Normung
E	Energy
EC	European Commission
EMC	Electro Magnetic Compatibility
EMI	Electromagnetic Interference
EMS	Energy Management System
EN	European Norm
EOL	End Of Life
EPBD	Energy Performance of Buildings Directive
EPR	Ethylene Propylene Rubber
ErP	Energy related Products
EuP	Energy using Products
EU	European Union
HD	Harmonization Document
HV	High Voltage
IEC	The International Electro technical Commission
IT	Information Technology
K	Kilo (10^3)
Kf	Load form factor
LCA	(environmental) Life Cycle Assessment
LCC	Life Cycle Costs
LV	Low Voltage
LVD	Low Voltage Directive
MEErP	Methodology for Ecodesign of Energy-related Products
MEEuP	Methodology for Ecodesign of Energy-using Products
MV	Medium Voltage
NBN	Bureau voor Normalisatie (België) - Bureau de Normalisation (Belgique)
PE	Polyethylene
PF	Power factor
PP	Polypropylene
PRODCOM	PRODuction COMmunautaire
PVC	Polyvinylchloride
R	Resistance
RCD	Residual Current Device

REMODECE	Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe
RES	Renewable Energy Sources
RMS	Root Mean Square
RoHS	Restriction of the use of certain Hazardous Substances in electrical and electronic equipment
S	apparent power
S	Section
SME	Small and Medium sized Enterprise
TBC	To Be Completed
TBD	To Be Defined
TC	Technical Committee
TR	Technical Report
UK	United Kingdom
V	Voltage
VITO	Flemish institute for Technological Research
XLPE	Cross-linked Polyethene
XLPVC	Cross-linked PVC

Use of text background colours

Blue: draft text
Yellow: text requires attention to be commented
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CHAPTER 3 TASK 3: USERS

The objective of this task is to identify the system aspects of the use phase. User requirements can be influenced by product design and product information. Relevant user-parameters are an important input for the assessment of the environmental impact of a product during its use and end-of-life phase, in particular if they are different from the standard measurement conditions as described in subtask 1.2.

With the recast of the Ecodesign Directive to energy-related products in 2009, the discussion on user requirements needs to take into account the indirect impacts of energy-related products (see illustration below).

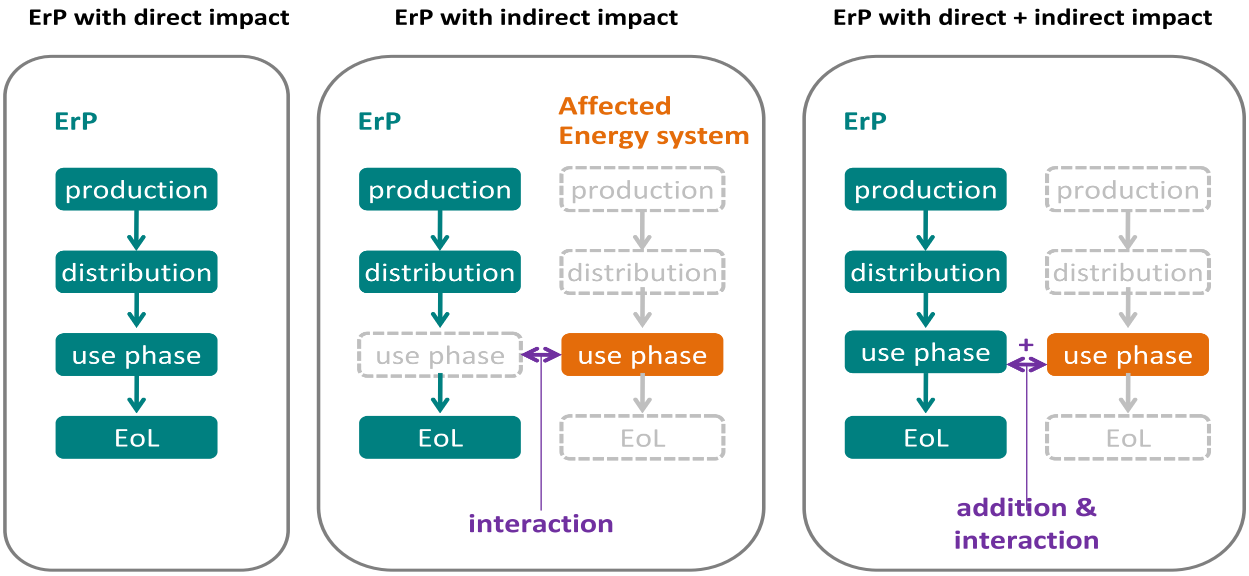


Figure 3-1: Three groups of ErP, distinguished by their impact (source: MEErP 2011 Methodology Part 1).

Summary of Task 3:
The use of the power cable is mainly defined by the characteristics of the circuit, the load distribution in the building and the power consumption profile of the connected loads.
The most important parameters for the circuit characteristics are the average circuit length (l) in meters (see Table 3-4) and minimum and maximum cable cross sectional areas (CSA) in mm² per circuit type (see Table 3-2).
The most important parameters related to the power consumption profile of the loads are: load factor (αc), load form factor (Kf) (see Table 3-13) and power factor (see 3.1.5.2).
There is a big spreading in these parameters and 'the European average electrical circuit' is not directly defined neither existing. This might introduce a large degree of

uncertainty in later tasks and therefore ranges of data are included which allow complementary sensitivity analysis in Tasks 6 and 7.

The product lifetime is summarized in Table 3-24. End-of-life parameters are listed in Table 3-17.

On user behaviour the stakeholder questionnaires[1] also revealed that:

- that electro-installers are unaware of the losses in circuits;
- in practice, calculation of losses is not performed when designing an installation. Mostly only voltage drop and safety restrictions are taken into account;
- The responsibility regarding the budget for the investment and the budget for operating expenses is in most cases split (and linked to different departments/persons). As a result no economic Life Cycle Cost (LCC) is performed and the installation with the lowest investment costs is selected. Tenders do not include a requirement to perform LCC calculations in the offer.

3.1 Systems aspects of the use phase for ErPs with direct impact

The main function of the electrical installation is to transport electricity. The installation consumes energy by fulfilling this function, because the transport experiences electrical resistance in different parts of the installation and part of the energy is dissipated as heat energy. In this study the focus is on the power cable used in the electrical installation. The power cable is part of the electric circuit (see Figure 3-1 and 3-2). The electric circuit consists of different segments using power cables, junction boxes, terminal connections and protection equipment like circuit breakers limiting the maximum current in the power cable. The electrical installation consists of several circuits, distribution boards/system board, and overall protection devices. The electrical installation is an indispensable part of modern buildings.

[1] http://www.erp4cables.net/node/6, this questionnaire was sent to installers on the 30th of September, 2013 in the context of this study. A second questionnaire was sent on the 7th of July, 2014. The results were combined.

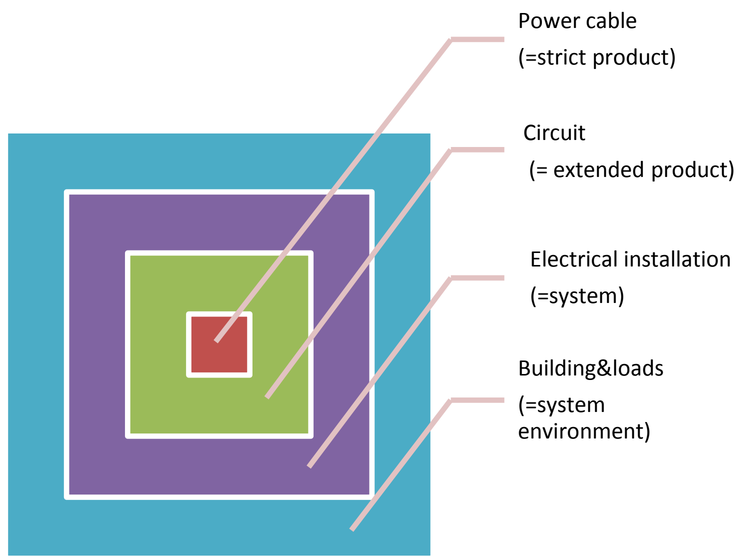


Figure 3-2: From strict product to systems approach

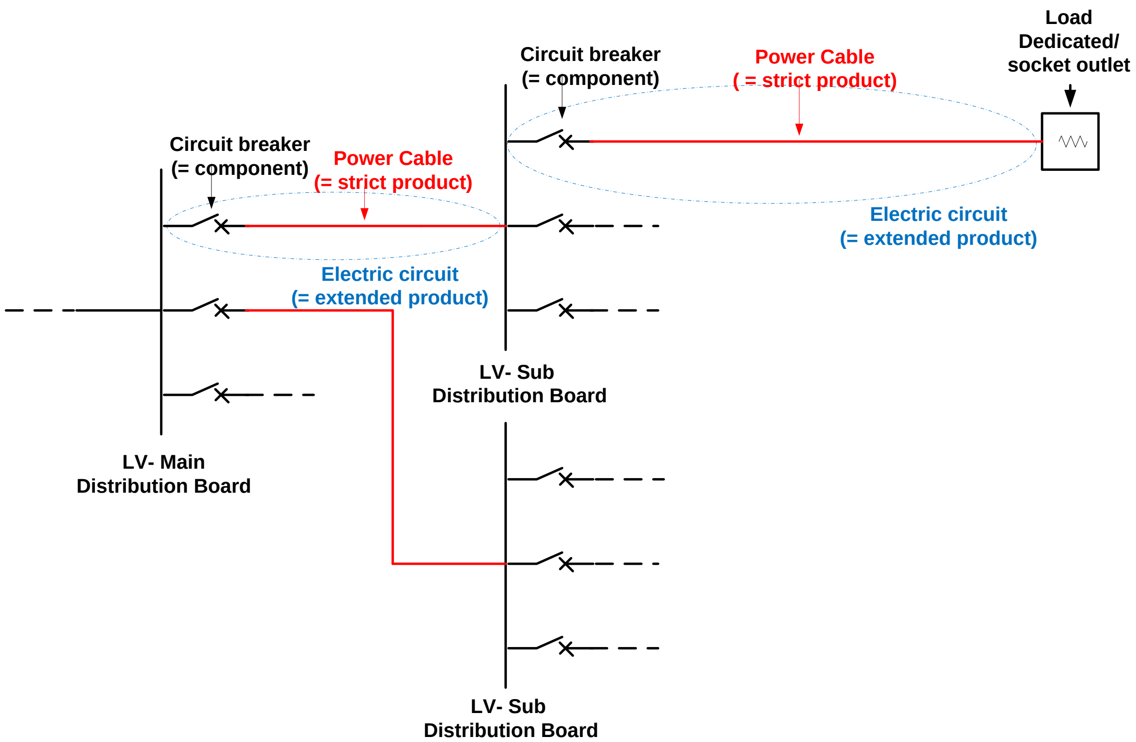


Figure 3-3: Simplified 1-wire diagram of an electric installation

The use of the power cable is mainly defined by the characteristics of the circuit, the load distribution in the building and the profile of the loads (in time).

3.1.1 Definition of the user and context

For electrical installation it is important to discriminate between different types of users who use cables:

1. The engineering company or architect of the electrical installation.
2. The person or organisation performing the actual installation of electrical installation of a new building or renovation of parts of the building, e.g. electrical contractors, interior designers, property developers and installers, hereafter called the *'installers'.* The installer is responsible for putting the electrical installation including the power cables into service.
3. The person or organisation responsible or certifying the electrical installation, hereafter called the *'certifier'.*
4. The end-user who lives or works in the building and makes use of the electrical installation, hereafter called the *'user'*.
5. The owner of the building and thus of the electrical installation, hereafter called the *'owner'*. The owner finances the electrical installation and has the end-responsibility for the electrical installation in the building (certification, safety coordinator, etc.). Depending on the sector and function type of the building the owner and user roles may be unified in one organisation/person.

Depending on the sector and country the installer and user can be the same acting as a Do-It-Yourself (DIY) consumer. In some countries the installer can also perform the certification of a (small) installation. The DIY method however is only applied in the residential building sector.

3.1.2 Loss parameters directly related to the cable itself

As discussed in Task 1, the power losses are proportional to the cable resistance (R). The resistance of a cable in circuit at a temperature t can be calculated by the formula:

$$R = \rho_t . l/A \text{ (Ohm)} \qquad \text{(formula 3.1)}$$

The losses in a power cable are therefore affected by:

- the specific electrical resistance (ρ_t) of the conductor material;
- the cross-sectional area (A) of the cable;
- the total length (l) of cable for a circuit.

In annex B of Task 1, a closer look is taken at these physical parameters and at how manipulation of these parameters can contribute to smaller power losses in power cables.

3.1.2.1 Conductor material electrical resistance

Both aluminium and copper are used as conductors and are available for use in standard wire sizes and foils. Aluminium is less used in cables with small CSAs.

Table 3-1: Properties of Aluminium and Copper

Property	Aluminium	Copper
Electrical Conductivity (relative)	0.61	1
Thermal Conductivity (Cal/s.cm.K)	0.57	0.94
Relative weight for the same conductivity	0.54	1
Cross section for the same conductivity	1.56	1
Tensile Strength (kg/cm^2)	844	2250
Specific weight (kg/dm^2)	2.7	8.9
Electrical Resistivity (mOhm.mm) (20°C)	26.5	16.7
Thermal coefficient of resistance (1e-6/K)	3770	3900

3.1.2.2 Cross-sectional area (CSA)

The available CSAs for power cable are defined by standardisation and are expressed in mm². The following values for CSA are used in IEC 60228:2004: 0.75; 1; 1.5; 2.5; 4; 6; 10; 16; 25; 35; 50; 70; 95; 120; 150; 185; 240; 300; 400; 500; 630; 800; 1000 and 1200 mm².

According IEC 60364-1 the CSA of conductors shall be determined for both normal operating conditions and for fault conditions according to:

- their admissible maximum temperature;
- the admissible voltage drop;
- the electromechanical stresses likely to occur due to earth fault and short-circuit currents;
- other mechanical stresses to which the conductors can be subjected;
- the maximum impedance with respect to the functioning of the protection against fault currents;
- the method of installation.

The selection of the appropriate cable cross sectional area takes into account specific parameters like:

- their maximum admissible intensity;
- requested current-rating capacity by the circuit;
- length of the cable in the circuit;
- maximum allowed voltage drop;
- installation conditions (ambient temperature and installation type);
- maximum operating temperature for cables and the full installation;
- safety fuses, circuit breakers and short circuit time;
- number of cables per circuit.

Table 3-2: Minimum and maximum cable cross-sectional areas per circuit type

Sector	Circuit application type	CSA (mm²) min	CSA (mm²) max
Residential	Distribution circuit	6	16
	Lighting circuit	1	2.5
	Socket-outlet circuit	1.5	6[2]
	Dedicated circuit	2.5	6
Services	Distribution circuit	10	600
	Lighting circuit	1.5	2.5
	Socket-outlet circuit	1.5	6
	Dedicated circuit	2.5	95
Industry	Distribution circuit	25	600
	Lighting circuit	1.5	2.5
	Socket-outlet circuit	1.5	10[3]
	Dedicated circuit	2.5	600

3.1.2.3 Length of cable

The length of cable is primarily determined by the physical topography and design of the building, the building's function type and the placing of the appliances along the building. The length of cable used in the electrical installation is also determined by the topology of the electrical installation. For instance an installation can have one or more distribution levels.

Conclusion:
See data on lengths of cables in electrical circuits in section 3.1.4.5.

3.1.2.4 Number of cores

A power cable contains one or more conductor cores. When the cable is placed in conduits multiple single-core cables can be used. Some products consist of a combination of singe-core or multicore cable and flexible conduits. The number of cores is determined by:

- The AC grid system (TT,TN,IT), see Task 1
- Single phase or three-phase system
- Earthing conductor included or not, neuter conductor included or not
- Also the handling of the cable (multi-core cables with large CSAs are more difficult to handle than multiple single-core cables) and the product availability/existence play a role in cable selection.

The cores in a cable generally have the same CSA, but can also have different CSA. The phase currents in three phase systems tend to cancel out one another, summing to

[2] 5G6 mm² cable at 3-phase 400Vac and max 3% voltage drop results in maximum circuit length of 132m and Imax of 16A or maximum circuit length of 53m and Imax of 40A.
[3] 5G10 cable at 3-phase 400Vac and max 3% voltage drop results in maximum circuit length of 142m and Imax of 25A or maximum circuit length of 56m and Imax of 63A.

zero in the case of a linear balanced load. This makes it possible to reduce the size of the neutral conductor or even to leave it out in the ideal situation.

3.1.2.5 Skin effect

The skin effect is the tendency of an alternating electric current (AC) to become distributed within a conductor such that the current density is largest near the surface of the conductor, and decreases with greater depths in the conductor. It has an effect on the cable resistance and is partly determined by the used conductor material and CSA of the cable. The electric current flows mainly at the 'skin' of the conductor, between the outer surface and a level called the skin depth δ. The skin effect causes the effective resistance of the conductor to increase at higher frequencies where the skin depth is smaller, thus reducing the effective cross-section of the conductor.

$$\delta = \sqrt{2\rho/\omega\mu} \quad \text{(formula 3.2)}$$

Where

ρ = resistivity of the conductor
ω = angular frequency of current = $2\pi \times$ frequency
μ = absolute magnetic permeability of the conductor

At 50 Hz in copper, the skin depth δ is about 9.2 mm. For aluminium it is about 11.6 mm.

The skin effect is only relevant for cables with a diameter D much larger than the skin depth. Using a material of resistivity ρ we then find the AC resistance of a wire of length L to be:

$$R \approx L\rho/(\pi(D - \delta)) \quad \text{(formula 3.3)}$$

At 50 Hz the skin effect is negligible for cables with a CSA of less than 400 mm². For cables with a very large CSA the skin effect is an important factor. For instance for cables with a CSA of 1000 mm² the AC resistance compared to the DC resistance will increase with almost 30% for copper and 14 % for aluminium. Figure 3-4 shows the increase in resistance for copper and aluminium conductors at 50Hz for CSAs from 400 mm² till 1200 mm².

An S+x strategy for cables with a CSA of more than 400 mm² will therefore be countered by the increasing resistance due to the skin effect. Looking at material use versus savings the strategy will become less efficient for cables with a very large CSA.

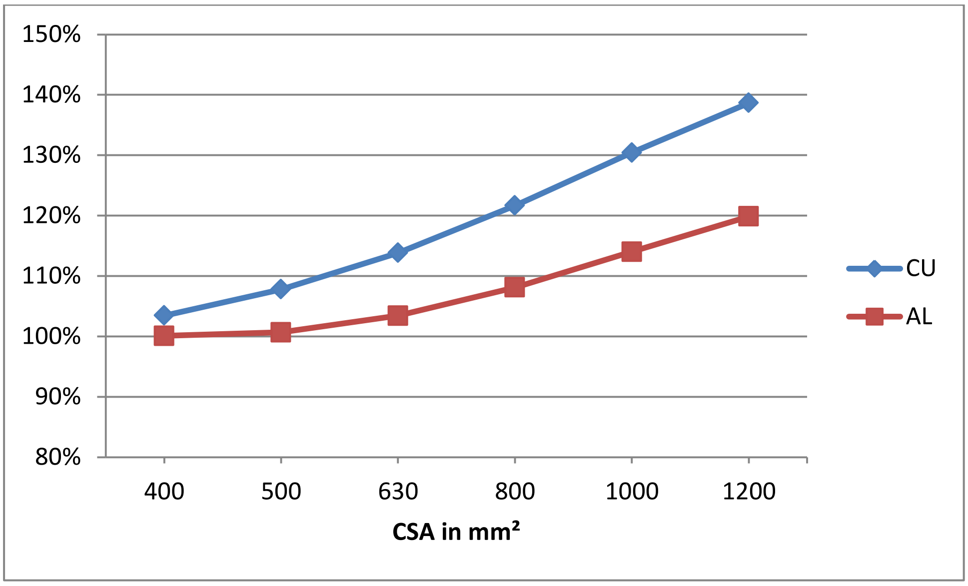


Figure 3-4: Resistance increase due to skin effect at 50Hz for Cu and Al conductors

Conclusion:
The skin effect is only relevant for power cables with very large CSA. From 400 mm² on the effect is noticeable, and becomes relevant for CSAs more than 630 mm². When selecting the appropriate measure for energy savings in power cables with a very large CSA, the skin effect should be taken into consideration. From a certain CSA magnitude on a dual-wiring strategy (with a smaller CSA than the S+x strategy) may be preferred upon an S+x strategy.

3.1.3 Other functional cable parameters not directly related to losses

3.1.3.1 Insulation material

The selection criteria of insulation material depend on electrical (rated voltage) and physical (temperature range, flexibility, flammability, chemical resistance, etc.) requirements of the application.

The selection of insulation material is also influenced by building properties and function of the building (risk of fire, evacuation capability, etc.). For instance, in Belgium the national code AREI imposes requirements on power cables regarding flame resistance. For buildings higher than 25 meter, schools, hospitals and so on the evacuation velocity is one of the factors determining the flame resistance category (elapsed time).

3.1.3.2 Construction of the conductor

The type of construction mainly has an effect on the flexibility/bending radius. The selection of the type of construction is thus largely determined by the flexibility and bending requirements.

The construction type has also a small effect on the AC resistance of the cable. Table 3-3 shows the influence of the construction type on the maximum resistance at 20° C, based upon the resistance values for different CSAs and classes, listed in IEC 60228:2004. ΔR stands for the R_{classx} – R_{class1}. ΔR/R_{class1} indicates the amount of resistance reduction or increase for class x compared to class1.

Table 3-3: Construction type versus maximum resistance (at 20° C)

	Class 1 solid conductors for single-core and multicore cables	Class 2 stranded conductors for single-core and multi-core cables		Class 5 flexible copper conductors for single-core and multi-core cables		Class 6 flexible copper conductors for single-core and multi-core cables	
CSA	Plain	Plain wires	ΔR/Rclass1	Plain wires	ΔR/Rclass1	Plain wires	ΔR/Rclass1
mm²	Ω/km	Ω/km	%	Ω/km	%	Ω/km	%
0.5	36	36	0.0%	39	8%	39	8%
0.75	24.5	24.5	0.0%	26	6%	26	6%
1	18.1	18.1	0.0%	19.5	8%	19.5	8%
1.5	12.1	12.1	0.0%	13.3	10%	13.3	10%
2.5	7.41	7.41	0.0%	7.98	8%	7.98	8%
4	4.61	4.61	0.0%	4.95	7%	4.95	7%
6	3.08	3.08	0.0%	3.3	7%	3.3	7%
10	1.83	1.83	0.0%	1.91	4%	1.91	4%
16	1.15	1.15	0.0%	1.21	5%	1.21	5%
25	0.727	0.727	0.0%	0.78	7%	0.78	7%
35	0.524	0.524	0.0%	0.554	6%	0.554	6%
50	0. 387	0.387	0.0%	0.386	0%	0.386	0%
70	0.268	0.268	0.0%	0.272	1%	0.272	1%
95	0.193	0.193	0.0%	0.206	7%	0.206	7%
120	0.153	0.153	0.0%	0.161	5%	0.161	5%
150	0.124	0.124	0.0%	0.129	4%	0.129	4%
185	0.101	0.0991	-1.9%	0.106	5%	0.106	5%
240	0.0775	0.0754	-2.7%	0.0801	3%	0.0801	3%
300	0.062	0.0601	-3.1%	0.0641	3%	0.0641	3%
Average			-0.4%		5.6%		5.6%

3.1.4 Loss parameters directly related to the electrical circuit and network topology

Losses are also related to the electrical circuit and network topology.
An electrical circuit starts at a distribution board and consists of a protective device, cable, junction boxes and distribution endpoints all being part of the electrical circuit.
Also the network topology has an impact, which are the relative positions and the interconnections of the circuit elements representing an electric circuit.
In the following sections parameters are defined and reference data is included to model relevant parameters related to cable losses.

3.1.4.1 Single phase or three phase circuit

Being a single or three phase circuit has mainly an effect on the number of cores of the cable (or number of single core cables) used in the circuit. A single phase circuit cable will have two cores (phase and neuter) or three cores (phase, neuter, earthing). A three phase circuit cable canl have three cores (three phases), four cores (phases and earthing, phases and neuter) or five cores (phases, neuter, earthing).

The voltage used in the single phase system is 230V.
The voltage used in the three phase system can be 230VAC or 400VAC, depending the configuration. To transport the same energy in a three phase 400V system as in a single phase 230 V system the current can be reduced and hence losses are lower. High power loads in the service sector and industry, i.e. above 4600 VA (230VAC/20A), are therefore most often connected 400 VAC three phase.

Conclusion:
In this study we will assume that all loads above 4600 VA are connected three-phase, a sensitivity analysis in Task 7 could check for a single phase 230 VAC.
Lighting circuits and socket outlet circuits will be considered single phase.
Three phase socket outlet or connector circuits do exist and will be reconsidered in a sensitivity analysis in Task 7.

3.1.4.2 Maximum voltage drop in a circuit

The maximum voltage drop in a circuit (see Figure 3-5) is determined in standard (IEC 60364-5-52 – informative Annex G), see Task 1. The voltage drop is directly proportional to the power loss.

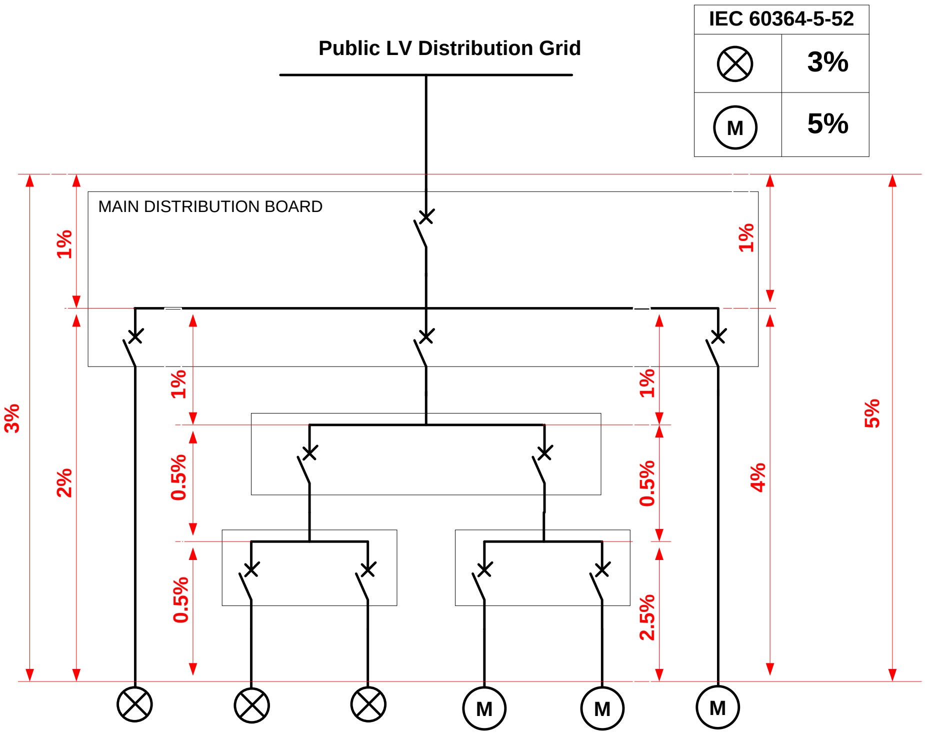


Figure 3-5: Voltage drop in an electrical installation

3.1.4.3 Overcurrent protection in a circuit

Cable losses are limited because the maximum current or overcurrent is limited in an electrical circuit by using circuit breakers or fuses, as discussed in Task 1.
The overcurrent device rating (In) is selected so that In is greater than or equal to the load current (Ib). Ib is the design current of the circuit, i.e. the current intended to be carried by the circuit in normal service (see task 1).

Circuit breakers are installed according to standard IEC 60364-1.

3.1.4.4 Circuit network topology

Electrical circuits can be installed in various network topologies.

In lighting circuits three different topologies are common:

- A 'Bus network topology' approach, e.g. this is most often implemented with a so-called DALI[4] bus where a control signal is distributed together the power cable. This is frequently used in large industrial installations. Typically a five wire cable is used (5G1.5) whereby two wires are used for the control signal.
- 'Two-wire installation' that contains only one wire between switch and lamp. In this system the switch/control product is connected in series with lamp/load and the neutral is not present in the switch (except in some countries). The advantage is the low amount of required copper wire and reduced short circuit risk during installation but the disadvantage is that no direct power supply is available for electronic control switches (e.g. dimmers). In Figure 3-6 an example of a 'two wire installation' of a two wire installation is shown. The neutral wire is directly going to the lamp, without intermediate switch.

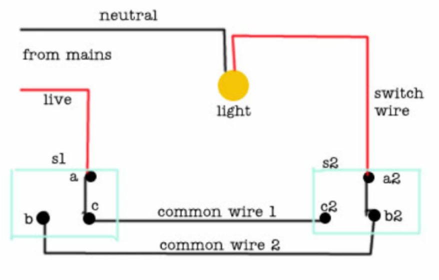


Figure 3-6: Example of a 'two wire installation'

- 'Three wire installation' that contains both the neutral and phase wire between the switch and the lamp. The main advantage is that a power supply for the control switch can easily be obtained but it requires more copper wire for installation.
- A single wire topology with a relays either at the lamp or at a central distribution board.

[4] http://www.dali-ag.org

In most European countries socket-outlets are interconnected with a single line, in the UK a ring circuit topology is used.

Conclusion:
The following topologies will be assumed as typical:

- For lighting in the industry and service sector: a DALI bus cable network topology;
- For socket-outlet: a single line topology;
- For dedicated loads: a point to point connection.

3.1.4.5 Circuit length

Length of circuit stands for the total amount of cable used for the circuit between distribution board (start point of the circuit) and final endpoint of a circuit.

The average length in meters of a circuit, based upon the responses on the questionnaire for installers[5], per circuit type and sector is shown in Table 3-4.

Table 3-4: Average circuit length in meters according questionnaire[5]

Sector	Circuit application type	Average length min (m)	Average length ref (m)	Average length max (m)
Residential	Distribution circuit	15	21	54
	Lighting circuit	10	20	60
	Socket-outlet circuit	5	24	100
	Dedicated circuit	5	18	80
Services	Distribution circuit	20	56	200
	Lighting circuit	12	44	240
	Socket-outlet circuit	10	53	300
	Dedicated circuit	10	51	300
Industry	Distribution circuit	30	83	240
	Lighting circuit	20	68	340
	Socket-outlet circuit	15	72	500
	Dedicated circuit	15	79	400
CorrectionFactor		1	1	2

Conclusion:
Table 3-4 shows the average circuit lengths. The proposal is to use the average reference length values listed in Table 3-4 for the calculation of losses in circuits. Crosschecks in later tasks indicated that the maximum average value should be larger.

[5] http://www.erp4cables.net/node/6, this questionnaire was sent to installers on the 30th of September, 2013 in the context of this study. A second questionnaire was sent on the 7th of July, 2014. The results were combined.

This correction (results are multiplied with the corresponding correction factor shown in the last row of the table) is already incorporated in the results listed in Table 3-4. The maximum and minimum values are used for sensitivity analysis.

3.1.4.6 Effect of load distribution

In the case of socket-outlets electrical wires are 'branched' to distributed loads and hence losses are not equal within all cable segments. Figure 3-7 shows a typical wiring diagram with branches, the cable loading at the end points or sockets is of course lower compared to the central feeder connection.

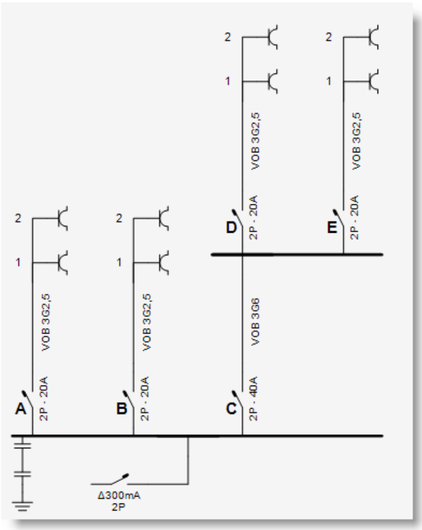


Figure 3-7: Typical wiring diagram

As explained in Task 1, the Kd 'distribution factor' is introduced to compensate the distribution of the loading over the cable of a circuit. A 'distribution factor' of 1 means that all cable segments are loaded with the same load current. The Kd 'distribution factor' is lower than or equal to 1.

Table 3-5: Kd factors for circuits with minimum 1 to maximum 8 socket-outlets with equally distributed loads and cable segment lengths

	Number of socket-outlet							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Kd	1	0.61	0.50	0.45	0.42	0.40	0.39	0.38

Table 3-5 shows the calculated Kd factor for circuits with up to 8 socket outlets, equally distributed loads and cable segment lengths. The calculation results for 8 nodes can be found in Annex 3-A in Table 3-25, Table 3-26, Table 3-27 and Table 3-28.
Table 3-6 and Figure 3-8 show the Kd factor for up to 30 nodes in function of the load branch length factor of respectively 1%, 10%, 50%, 100%, 150% and 200%. One can

conclude that the effect of the number of nodes on the Kd factor beyond 10 nodes is minimal.

Table 3-6: Kd factors for circuits with up to 30 nodes in function of load branch length factor

Load branch length factor	**Number of nodes**														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1%	1	0.624	0.517	0.467	0.438	0.420	0.406	0.397	0.389	0.383	0.378	0.374	0.371	0.368	0.366
10%	1	0.613	0.502	0.451	0.422	0.403	0.390	0.381	0.373	0.367	0.362	0.358	0.355	0.352	0.350
50%	1	0.563	0.437	0.382	0.351	0.332	0.319	0.309	0.302	0.296	0.292	0.288	0.285	0.282	0.280
100%	1	0.500	0.356	0.295	0.262	0.242	0.229	0.220	0.213	0.207	0.203	0.200	0.197	0.194	0.192
150%	1	0.438	0.274	0.208	0.173	0.153	0.140	0.130	0.124	0.119	0.115	0.111	0.109	0.106	0.105
200%	1	0.375	0.193	0.121	0.084	0.064	0.050	0.041	0.035	0.030	0.026	0.023	0.021	0.019	0.017

Load branch length factor	**Number of nodes**														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1%	0.363	0.362	0.360	0.358	0.357	0.356	0.355	0.354	0.353	0.352	0.351	0.350	0.350	0.349	0.348
10%	0.348	0.346	0.344	0.343	0.341	0.340	0.339	0.338	0.337	0.336	0.336	0.335	0.334	0.334	0.333
50%	0.278	0.276	0.275	0.273	0.272	0.271	0.270	0.269	0.268	0.267	0.267	0.266	0.265	0.265	0.264
100%	0.190	0.189	0.187	0.186	0.185	0.184	0.183	0.183	0.182	0.181	0.181	0.180	0.180	0.179	0.179
150%	0.103	0.102	0.100	0.099	0.098	0.098	0.097	0.096	0.096	0.095	0.094	0.094	0.094	0.093	0.093
200%	0.016	0.014	0.013	0.012	0.012	0.011	0.010	0.010	0.009	0.009	0.008	0.008	0.008	0.007	0.007

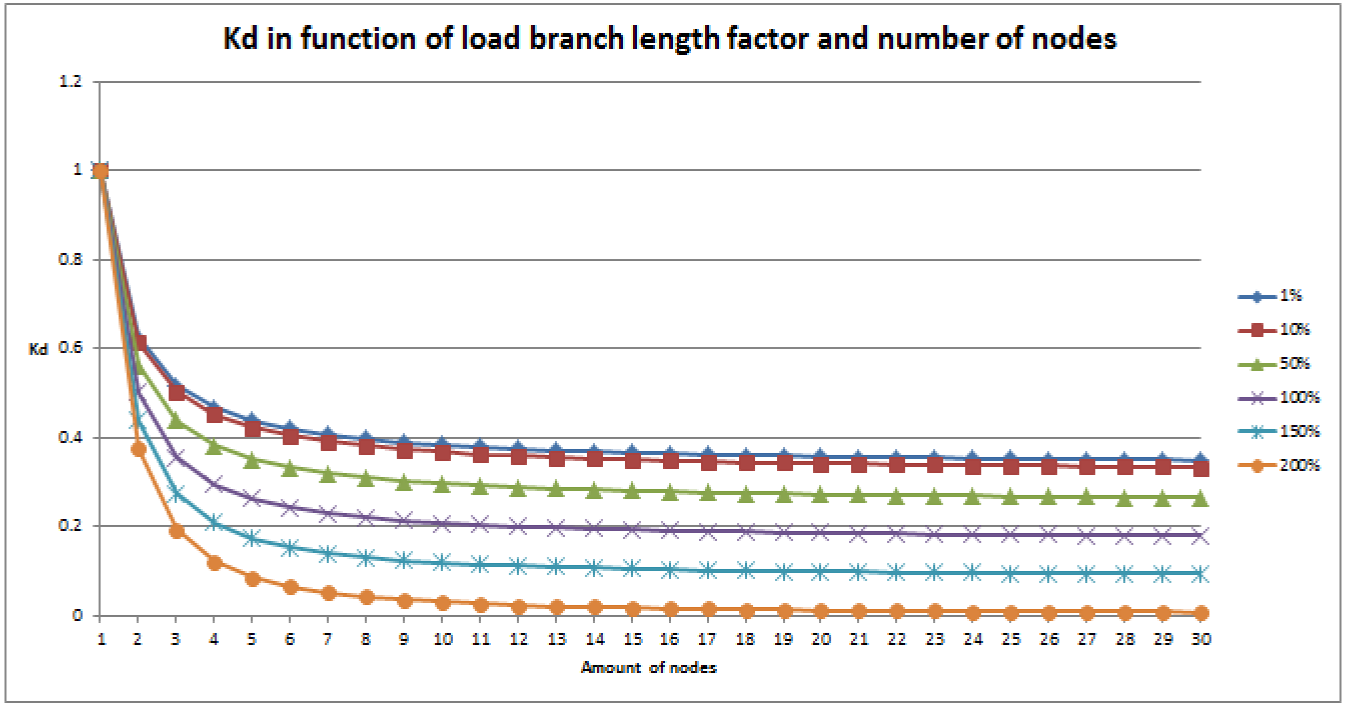


Figure 3-8: Kd in function of load branch length factor and number of nodes

Table 3-7: Average number of nodes per circuit application type according to questionnaire[6]

Sector	Circuit application type	Average number min	Average number ref	Average number max
Residential	Distribution circuit	1	1	1
	Lighting circuit	5	10	30
	Socket-outlet circuit	8	10	20
	Dedicated circuit	1	2	3
Services	Distribution circuit	1	1	1
	Lighting circuit	3	12	25
	Socket-outlet circuit	4	8	15
	Dedicated circuit	1	2	6
Industry	Distribution circuit	1	1	1
	Lighting circuit	3	14	28
	Socket-outlet circuit	2	6	10
	Dedicated circuit	1	2	5

Typical circuits have almost no branches. The cables are wired through at the nodes. Therefor a load branch length factor of 1% is used to calculate the Kd factor based upon the number of nodes in Table 3-7. The values in Table 3-8 are extracted from Table 3-6 based upon the number of nodes in Table 3-7.

[6] http://www.erp4cables.net/node/6, this questionnaire was sent to installers on the 30th of September, 2013 in the context of this study. A second questionnaire was sent on the 7th of July, 2014. The results were combined.

Table 3-8: Kd factor per circuit type

Sector	Circuit application type	Kd if low number of nodes	Kd avg	Kd if high number of nodes
Residential	Distribution circuit	1.00	1.00	1.00
	Lighting circuit	0.44	0.39	0.35
	Socket-outlet circuit	0.40	0.39	0.36
	Dedicated circuit	1.00	1.00	0.52
Services	Distribution circuit	1.00	1.00	1.00
	Lighting circuit	0.52	0.37	0.35
	Socket-outlet circuit	0.47	0.40	0.37
	Dedicated circuit	1.00	1.00	1.00
Industry	Distribution circuit	1.00	1.00	1.00
	Lighting circuit	0.52	0.37	0.35
	Socket-outlet circuit	0.62	0.44	0.38
	Dedicated circuit	1.00	1.00	1.00

Note: in distributed and in most dedicated circuits the loads are concentrated at the end of the circuit, resulting in a Kd factor of one.

Conclusion:
Table 3-8 summarises the proposal for average values to be used in this study.

3.1.4.7 Effect of not simultaneous functioning of distributed loads

Socket-outlets are connected to multiple loads and when they are not functioning simultaneously this will decrease load current in the circuit. Because losses are proportional to square of the loading current, the losses will be lower. This can be modelled by the so-called 'Rated Diversity Factor'. However, when considering all the loads served by one circuit as one aggregated load, this factor isn't necessary. The diversity factor effect is then incorporated in the load factor and load form factor of the 'circuit load'.

Conclusion:
By using load factor and load form factors associated with a 'circuit load', this factor can be omitted.

3.1.4.8 Ambient temperature

Conductor losses are temperature dependent and therefore higher ambient temperatures have a negative effect on the losses and the current-carrying capacity of the cable. For instance, according IEC 60364-5-52 a correction factor of 0.87 has to be applied for PVC cables installed in locations with a ambient temperature of 40°C.

Conclusion:

An ambient temperature of 20°C will be assumed, because this is the normal indoor temperature.

3.1.4.9 Temperature effect caused by the 'method of installation'

Conductor losses are temperature dependent and therefore also the so-called method of installation influences the losses and hence the current-carrying capacity of the cable. This effect is included in standard IEC 60364-5-52 which defines correction factors according to the installation method. IEC 60364-5-52 describes 73 reference installation methods. For each method different correction factors are defined to calculate the current carrying capacity. Figure 3-9 shows some examples of methods of installation and Figure 3-10 the most typical thermal conditions.

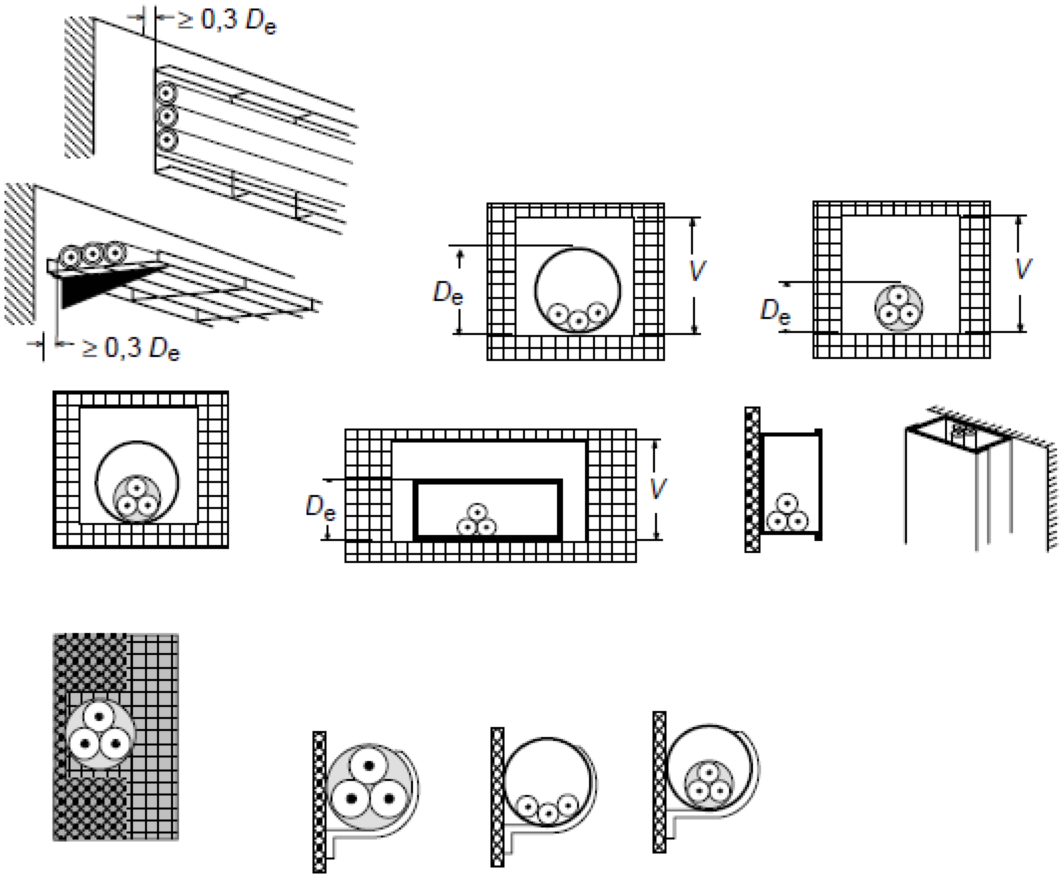


Figure 3-9: Some examples of method of installation (IEC 60364-5-52)

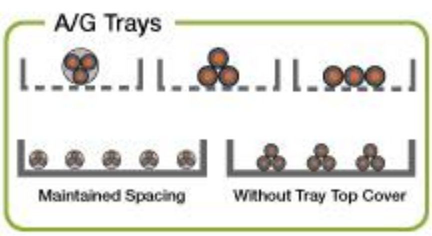


Figure 3-10: Different thermal conditions

Conclusion:
The correction factors in IEC 60364-5-52 related to the method of installation have an impact on the selection of the cross section of a cable (fixed current carrying capacity), or on the current carrying capacity (fixed cross section). The cross section and the current carrying capacity are incorporated in the formulas calculating the losses in a circuit (see formula 3.4 and 3.7).

3.1.4.10 Single or three phase system

See also 3.1.4.1. Of course, in order to have a three phase load connection a three phase grid connection is required.

Conclusion:
See 3.1.4.1.

3.1.4.11 Number of distribution levels

An electrical installation has one or more distribution levels (see definition in Task 1). Small installations have just one level. Larger installations in general have two levels. Exceptionally, very large installations or installations with special design requirements may have a third level.

Conclusion:
No statistics on distribution levels is available. Therefore, two levels will be regarded as a reference design in the industry and service sector.

3.1.4.12 Rated Diversity Factor DF at installation level

The Diversity Factor according IEC 61439-3 recognizes that multiple functional units (in this case outgoing circuits at a distribution board or assembly) are in practice not fully loaded simultaneously or are intermittently loaded. The Diversity Factor should be used when calculation the total load in an distribution board/assembly and higher level based upon the sum of the loads in the outgoing circuits of the distribution board.

Different Rated Diversity Factor may be stated for groups of outgoing circuits or for all the outgoing circuits of the assembly/distribution board. Within each of these groups, including the complete assembly, the sum of the rated currents multiplied by the Rated Diversity Factor shall be equal to or higher than the assumed loading currents.

IEC 61439-3 states that in case of lack of information relating to the actual load currents, the Manufacturer will select and declare appropriate Rated Diversity Factor values, preferably from the conventional values listed in in Table 3-9.

Table 3-9: Diversity factor in function of the number of circuits according IEC 61439-3

Number of outgoing circuits	Diversity Factor (DF)
2 and 3	0,8
4 and 5	0,7
6 to 9 inclusive	0,6
10 and above	0,5

Conclusion:
This factor should be used when the total load is calculated in function of the loading of each outgoing circuit at the specific distribution level. However, in task 4 till task 7 the base cases and their associated parameters are specified at circuit level and not at electrical installation level. Consequently, this factor isn't relevant for this study. See also conclusion in 3.1.4.7.

3.1.5 Parameters related to the building and loading

Losses in cables depend on the current loading, the relevant loading parameters are explained hereafter.

3.1.5.1 Load Factor (α_c) and load form factor (Kf)

This section describes the used Load factors (α_c =Pavg/S) and Load Form factors (Kf = Prms/Pavg) as defined in chapter 1. To simplify the calculation the loads served by a circuit is regarded as one single virtual load at the end of the circuit (this the reason why α_c and not α is used; α_c stands for corrected or circuit load factor). The Kd distribution factor will compensate this change in topology. The diversity of the different single loads is incorporated into the virtual load.

The load factor α_c is in between 0 and 1. The Load Form factor is always larger than or equal to 1. The product of the load factor and the load form factor is always less than or equal to 1.

Clearly in real conditions current loading (I) (and temperature) have an important influence. In order to calculate the annual energy loss of cables from data files with an estimation of the current loading, it is convenient to switch to time independent parameters and use the so-called RMS load (Prms) or root-mean-square value of the power load load profile. The RMS load values can be computed from data files, e.g. from the Synthetic Load Profiles. The study will investigate which load form factors are most common and could be used in later tasks for assessment of base cases.

When calculating the losses in a circuit, the load profiles for each load of the circuit have to be known. These statistics are however not available. Synthetic Load Profiles are aggregated averaged load profiles of building units (households), and can differ largely from the load profile of a single circuit, and can therefore not be used.

Therefore some general assumptions are made in the calculation of the load and form factors. For instance office lighting[7] have typical annual operating hours ranging from

[7] Preparatory Studies for Eco-design Requirements of EuPs: 'Final report lot 8 on office lighting' (see www.eup4light.net)

2000-2500 hours per year which should be equivalent to a load factor (Pavg/S) = 2250h/8760h = 26 %. Assuming the lights are all switched on 2250h a year, and all are switched off the rest of the year results in a Kf equal to 1.96. In case of 2 periods with two distinct power usage P1 and P2, Kf is calculated as follows:

$$\mathrm{Kf} = \frac{\sqrt{\dfrac{period1\ x\ P1^2 + period2\ x\ P2^2}{period1 + period\ 2}}}{\dfrac{period1\ x\ P1 + period\ 2\ x\ P2}{period1 + period2}}$$

Table 3-10, Table 3-11 and Table 3-12 show the calculation of the load factors and load form factors and the assumptions made for this calculation. The calculation is performed per circuit type and per sector. For each of these combinations a low, a reference and a high value is provided.
There are two periods in this model: P1 period 1 and P2 period 2. The sum of the 2 periods is 168, which can be seen as 168 hours in one week. There are two load levels represented by P1 and P2. The ratio between the P2 and P1 load level is given by the P2/P1 ratio. In this model P1 was always 100 (high loading), and P2 (low loading) was always lower than P1. The absolute load values in this calculation have no influence on the calculation.

To calculate the load factor based upon periods, an additional use factor is introduced. The load factor is calculated as follows:

$$\alpha_c = \frac{period\ 1 + P2/P1\ x\ period\ 2}{period\ 1 + period\ 2}\ x\ use\ factor$$

The use factor indicates the ratio of the design load and the rated maximum load (current-carrying capacity) of the circuit. For instance when assuming 0.3 for a lighting circuit (circuit breaker 10 A, 230 Vac, i.e S= 2300 W) it means that the design load of the circuit is about 690 W.

The terms P2 period 2, Prms, Pavg, Kf, α_c and Kf.α_c are calculated. The other terms are input values and represent the assumptions.

Table 3-10: Load form factor and load factors in the residential sector

Residential												
	Lighting circuit			**Socket-outlet circuit**			**Dedicated circuit**			**Distribution circuit**		
	Low	**Ref**	**High**	**Low**	**Ref**	**High**	**Low**	**Ref**	**High**	**Low**	**Ref**	**High**
Use factor	0.2	0.3	0.4	0.1	0.2	0.3	0.3	0.4	0.5	0.05	0.1	0.3
P2/P1 ratio	1%	5%	10%	1%	10%	20%	1%	1%	1%	20%	30%	40%
P1 period 1	100	100	100	100	100	100	100	100	100	100	100	100
Period 1	14	21	28	5	15	25	4	7	14	70	80	90
P2 period 2	1	5	10	1	10	20	1	1	1	20	30	40
Period 2	154	147	140	163	153	143	164	161	154	98	88	78
Period 1 + Period 2	168	168	168	168	168	168	168	168	168	168	168	168
Prms	29	36	42	17	31	43	15	20	29	66	72	78
Pavg	9	17	25	4	18	32	3	5	9	53	63	72
Kf	3.12	2.11	1.67	4.38	1.74	1.34	4.61	3.99	3.12	1.24	1.14	1.08
α_c	0.02	0.05	0.10	0.00	0.04	0.10	0.01	0.02	0.05	0.03	0.06	0.22
Kf . α_c	0.06	0.11	0.17	0.02	0.06	0.13	0.05	0.08	0.14	0.03	0.07	0.23

Table 3-11: Load form factor and load factors in the services sector

Services												
	Lighting circuit			**Socket-outlet circuit**			**Dedicated circuit**			**Distribution circuit**		
	Low	**Ref**	**High**	**Low**	**Ref**	**High**	**Low**	**Ref**	**High**	**Low**	**Ref**	**High**
Use factor	0.4	0.5	0.7	0.2	0.3	0.4	0.6	0.7	0.8	0.6	0.7	0.8
P2/P1 ratio	10%	20%	30%	10%	20%	30%	10%	20%	30%	10%	20%	30%
P1 period 1	100	100	100	100	100	100	100	100	100	100	100	100
Period 1	50	60	70	50	60	70	70	80	90	70	80	90
P2 period 2	10	20	30	10	20	30	10	20	30	10	20	30
Period 2	118	108	98	118	108	98	98	88	78	98	88	78
Period 1 + Period 2	168	168	168	168	168	168	168	168	168	168	168	168
Prms	55	62	68	55	62	68	65	71	76	65	71	76
Pavg	37	49	59	37	49	59	48	58	68	48	58	68
Kf	1.50	1.27	1.16	1.50	1.27	1.16	1.37	1.21	1.13	1.37	1.21	1.13
α_c	0.15	0.24	0.41	0.07	0.15	0.24	0.29	0.41	0.54	0.29	0.41	0.54
Kf . α_c	0.22	0.31	0.48	0.11	0.19	0.27	0.39	0.49	0.61	0.39	0.49	0.61

Table 3-12: Load form factor and load factors in the industry sector

	Industry											
	Lighting circuit			**Socket-outlet circuit**			**Dedicated circuit**			**Distribution circuit**		
	Low	**Ref**	**High**	**Low**	**Ref**	**High**	**Low**	**Ref**	**High**	**Low**	**Ref**	**High**
Use factor	0.4	0.5	0.7	0.2	0.4	0.6	0.6	0.7	0.8	0.6	0.7	0.8
P2/P1 ratio	40%	50%	60%	40%	50%	60%	60%	75%	90%	52%	65%	78%
P1 period 1	100	100	100	100	100	100	100	100	100	100	100	100
Period 1	50	60	70	50	60	70	70	80	90	70	80	90
P2 period 2	40	50	60	40	50	60	60	75	90	52	65	78
Period 2	118	108	98	118	108	98	98	88	78	98	88	78
Period 1 + Period 2	168	168	168	168	168	168	168	168	168	168	168	168
Prms	64	72	79	64	72	79	79	88	95	76	84	90
Pavg	58	68	77	58	68	77	77	87	95	72	82	90
Kf	1.11	1.06	1.03	1.11	1.06	1.03	1.03	1.01	1.00	1.05	1.02	1.01
Lf	0.23	0.34	0.54	0.12	0.27	0.46	0.46	0.61	0.76	0.43	0.57	0.72
Kf . α_c	0.26	0.36	0.55	0.13	0.29	0.47	0.47	0.61	0.76	0.45	0.58	0.72

Conclusion:

Table 3-13 contains the summary of the load factors (α_c) and load form factors (Kf) calculated in Table 3-10, Table 3-11 and Table 3-12.

Table 3-13: Load factors (α_c) and load form factors (Kf) to be used in this study

		Lighting circuit			Socket-outlet circuit			Dedicated circuit			Distribution circuit		
		Low	Ref	High	Low	Ref	High	Low	Ref	High	Low	Ref	High
Residential sector	Kf	3.12	2.11	1.67	4.38	1.74	1.34	4.61	3.99	3.12	1.24	1.14	1.08
	αc	0.01	0.05	0.10	0.00	0.04	0.10	0.01	0.02	0.05	0.01	0.06	0.22
	Kf . αc	0.03	0.11	0.17	0.01	0.06	0.13	0.02	0.08	0.14	0.02	0.07	0.23
Services sector	Kf	1.50	1.27	1.16	1.50	1.27	1.16	1.37	1.21	1.13	1.37	1.21	1.13
	αc	0.07	0.24	0.41	0.04	0.15	0.24	0.14	0.41	0.54	0.14	0.41	0.54
	Kf . αc	0.11	0.31	0.48	0.06	0.19	0.27	0.20	0.49	0.61	0.20	0.49	0.61
Industry sector	Kf	1.11	1.06	1.03	1.11	1.06	1.03	1.03	1.01	1.00	1.05	1.02	1.01
	αc	0.12	0.34	0.54	0.06	0.27	0.46	0.23	0.61	0.76	0.22	0.57	0.72
	Kf . αc	0.13	0.36	0.55	0.06	0.29	0.47	0.24	0.61	0.76	0.23	0.58	0.72
αc correction factor		0.5	1	1	0.5	1	1	0.5	1	1	0.5	1	1

Crosschecks in later tasks indicated that the minimum average value is too high. This correction (results are multiplied with the corresponding correction factor shown in the last row of the table) is already incorporated in the results listed in Table 3-13. The maximum and minimum values are used for the sensitivity analysis

3.1.5.2 Power factor

The power factor is the real power used by the load divided by the apparent power required by the load conditions, see definition in Task 1.

Conclusion:
Although the power factor will differ from circuit to circuit depending on the load type, it is proposed to use PF = 0.8 (see IEC 60364-5-52/Annex G) as the default power factor.

3.1.5.3 Impact of harmonics

Current harmonics can cause extra losses due to the skin effect and uneven harmonics can cause overload current in the neutral wire[8]. Current losses depend on the type of load[9].
Harmonic current is limited by standard EN 61000-3-2, especially for lighting equipment.

Conclusion:

[8] Leonardo Energy Power Quality Initiative (2001), 'APPLICATION NOTE HARMONICS: CAUSES AND EFFECTS'
[9] Leonardo Energy Power Quality Initiative (2001), 'APPLICATION NOTE HARMONICS: CAUSES AND EFFECTS'

It is proposed to neglect these losses in further tasks.
Rationale: These losses are neglected because losses are already modelled by the fundamental load current (50 Hz) and more precise data on typical harmonic current of loads is missing.

3.1.5.4 Number of loaded conductors and impact of phase imbalance and harmonics

The number of loaded conductors in a single phase circuit is 2, i.e. the phase conductor and neutral conductor.

IEC 60364-5-52 article 523.6.1 states: " The number of conductors to be considered in a circuit are those carrying load current. Where it can be assumed that conductors in polyphase circuits carry balanced currents, the associated neutral conductor need not be taken into consideration. Under these conditions, a four-core cable is given the same current-carrying capacity as a three-core cable having the same conductor cross-sectional area for each line conductor. Four- and five-core cables may have higher current-carrying capacities when only three conductors are loaded.
This assumption is not valid in the case of the presence of third harmonic or multiples of 3 presenting a THDi (total harmonic distortion) greater than 15%.".

IEC 60364-5-52 article 523.6.2 states: "Where the neutral conductor in a multicore cable carries current as a result of an imbalance in the line currents, the temperature rise due to the neutral current is offset by the reduction in the heat generated by one or more of the line conductors. In this case, the neutral conductor size shall be chosen on the basis of the highest line current.".

IEC 60364-5-52 Annex E states: "Where the neutral current is expected to be higher than the line current then the cable size should be selected on the basis of the neutral current. If the neutral current is more than 135 % of the line current and the cable size is selected on the basis of the neutral current, then the three line conductors will not be fully loaded.".

Table 3-14 shows the reduction factors that should be applied to the design load to calculate the conductor section. For instance, consider a three-phase circuit with a design load of 39 A to be installed using four-core PVC insulated cable clipped to a wall, installation method C. A 6 mm² cable with copper conductors has a current-carrying capacity of 41 A and hence is suitable if harmonics are not present in the circuit. If 20 % third harmonic is present, then a reduction factor of 0.86 is applied and the design load becomes:39/086 = 45 A. As a result a 10 mm² cable is necessary.

Table 3-14: Reduction factors for harmonic currents in four-core and five-core cables[10]

Third harmonic content of line current %	Reduction factor	
	Size selection is based on line current	Size selection is based on neutral current
0 – 15	1,0	–
15 – 33	0,86	–
33 – 45	–	0,86
> 45	–	1,0

Conclusion:
The number of loaded conductors in a **single phase** circuit is **2**.

By lack of statistics on the imbalance in the line currents and the THDi in electric circuits, it is proposed to use a balanced system with a THdi of less than 15 % in this study. Consequently, the number of loaded cores in a 3-phase circuit is **3.**

3.1.6 Formulas used for power losses in cables

The general formulas for power losses and energy losses are the following:

- Power losses (in a cable) (Watt): the power losses at a certain moment of time t can be calculated by the following formula:

  $$P(t) = R.I^2(t) \text{ (Watt)} \quad \text{(formula 3.3)}$$

- The resistance of a cable at temperature t can be calculated by the following formula:

  $$R_t = \rho_t.l/A\ (\Omega) \quad \text{(formula 3.4)}$$

  where,
    - ρ_t= specific electrical resistance of the conductor at temperature t (Ω.mm²/m)[11]
    - l= length of the cable (meter)
    - A= cross sectional area of the conductor (mm²)

- Energy losses(E) according to the laws of physics:

  $$E = \int_0^T R.I^2(t) \quad \text{(formula 3.5)}$$

- Energy loss in cables according to IEC 60287-3-2:

  $$energy\ loss\ during\ the\ first\ year\ = \quad I^2max.\ RL\,.L.NP.NC\,.T \quad \text{(formula 3.6)}$$

  where,
    - Imax is the maximum load on the cable during the first year, in A;
    - RL is cable resistance per unit length;
    - L is the cable length, in m;

[10] IEC 60364-5-52
[11] ρ_t is the resistivity of conductors in normal service, taken equal to the resistivity at the temperature in normal service, i.e. 1,25 times the resistivity at 20 °C, or 0,0225 Ωmm²/m for copper and 0,036 Ωmm²/m for aluminium; IEC 60364-5-52 annex G

- NP is the number of phase conductors per circuit (=*segment in this context*);
- NC is the number of circuits carrying the same type and value of load;
- T is the equivalent operating time, in h/year.

Note: the formula used in IEC 60287-3-2 is only applicable to calculate the cable losses in a 'single cable segments' of a circuit.

- The formula in this study to calculate the annual energy loss (E (loss)) in a circuit cable based upon the above mentioned factors is:

$$E_{circuit,}(y)\ [kVAh] = Kd\ .\ R_t\ .\ Imax^2\ .\ (\alpha_c\ .\ Kf)^2\ .\ 8760\ /\ 1000 \qquad \text{(formula 3.7)}$$

where,

- Kd = the distribution factor
- R_t = cable resistance at temperature t (see formula 3.4)
- Imax = the maximum rated current of the cable
- α_c = The corrected load factor
- Kf = Load form factor (=Prms/Pavg)

Note: Prms requires the calculation of an integral of the load profile and therefore aligns with formula 3.5.

- The formula in this study to calculate the annual active energy (E (active)) transported via the circuit cable based upon the above mentioned factors is:

$$E_{active}(y)\ [kWh] = V\ .\ Imax\ .\ \alpha_c\ .\ Kf\ .\ PF\ .\ 8760\ /\ 1000 \qquad \text{(single phase)}$$

or

$$E_{active}(y)\ [kWh] = \sqrt{3}\ .\ V\ .\ Imax\ .\ \alpha_c\ .\ Kf\ .\ PF\ .\ 8760\ /\ 1000 \qquad \text{(three phase)}$$

(formula 3.8)

where,

- V = electrical installation voltage (V =230 for single phase and 400 for three phase)
- Imax = the maximum rated current of the cable
- α_c = The corrected load factor
- Kf = Load form factor (=Prms/Pavg)
- PF = the power factor of the load served by the power cable

- The next formula defines the loss ratio as the losses in the cable (formula 3.7) divided by the active energy transported via the circuit (formula 3.8):

$$\text{Loss ratio} = E_{circuit}(y) / E_{active}(y) \qquad \text{(formula 3.9)}$$

3.2 Systems aspects of the use phase for ErPs with indirect impact

The following systems are impacted in the use phase by the ErP.

3.2.1 Building space heating and cooling system

Cable losses are dissipated in the form of heat energy and therefore contribute to so-called 'internal heat gains', this has and impact on the building heating and cooling requirements. The impact can be positive when heating is needed or negative when cooling is needed.

Conclusion: because the impact can be positive or negative and it is not the primary function of the cable to contribute to the heating it is proposed to further neglect this effect in the study.

3.3 End-of-Life behaviour

General

Copper is a valuable material and therefore cables are in general returned for recycling. In 2009 recycled copper met 45.7% of Europe's copper demand[12]. In this process PVC insulation is separated mechanically from copper with shredders and granulators. The main purpose is to recover the valuable copper, but when transport cost are economically viable PVC insulation is also sold for recycling. Recycling of PVC can be done with Vinyloop technology[13]. Figure 3-11 shows the general recycling flow of power cables.

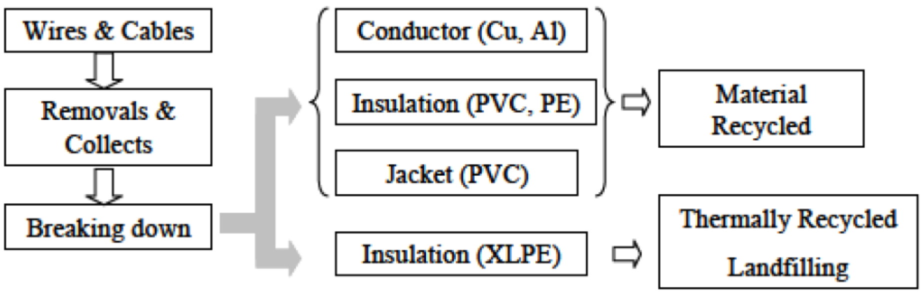


Figure 3-11: Recycling flow of wires and cables[14].

Stripping of the cable

According to a recent study by Flanders PlasticVision[14], metal recyclers with a focus on cables are mostly interested in the metals due to the copper and consider the plastic insulation as waste. Additionally, most of the European recyclers will only treat cables if they contain at least 40 to 45% copper as the shredder and separation costs will be too high to be economically viable in the case of lower copper content. Cable waste containing less copper is shipped towards low cost markets (e.g. China and India)

[12] http://eurocopper.org/copper/copper-information.html
[13] http://www.chemicals-technology.com/projects/ferrara/
[14] Proposal on material criteria for the product group: "Cables in closed circuit", May 2014, commissioned by OVAM.

where it is still economically viable to strip cables manually. An advantage of the manual process is the better separation of the materials and therefor a higher purity can be obtained. The volume of this shipped waste is told to be more than 50% of the collected cable waste.

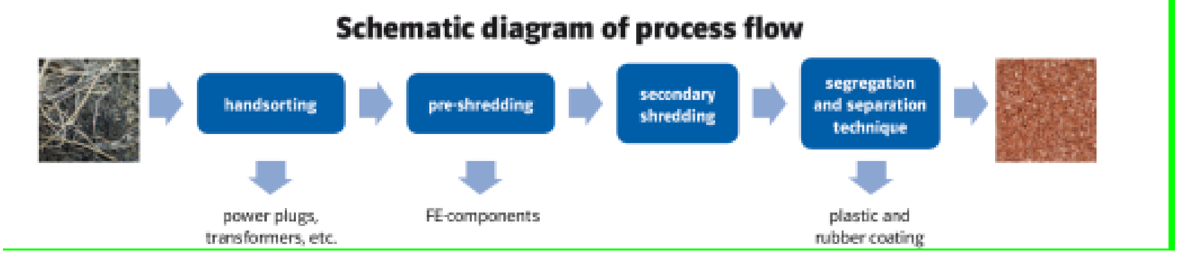


Figure 3-12: Schematic diagram of mechanical recycling process[14], see Figure 3-14 for more details.

The study[14] also mentions that not all cable waste is collected as a mixture of copper and plastic insulation. This is the case when the workload of electric installation companies is low and that those companies will strip cable waste themselves with basic stripping machines (see Figure 3-13) in order to get higher copper prices. Plastic waste that is generated during this process always ends up in the mixed waste. In Figure 3-13: Basic cable stripping machines14. *Table 3-15* the advantages and disadvantages are given between a mechanical or manual separation process of cables.

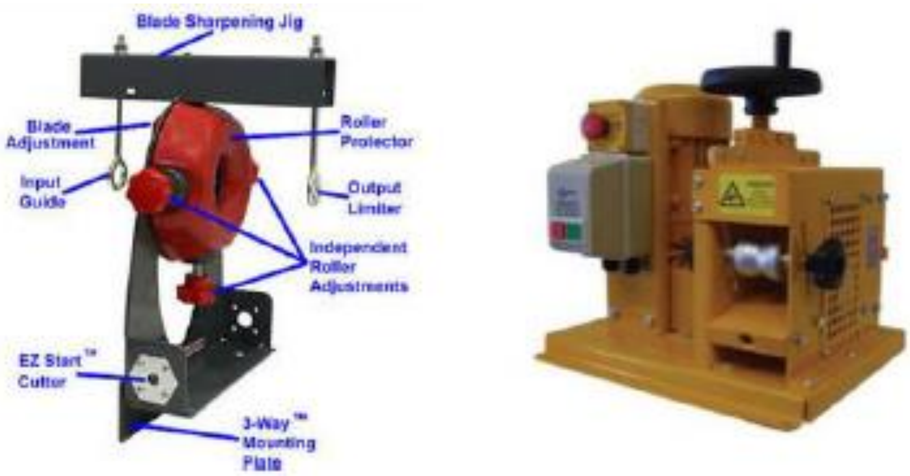


Figure 3-13: Basic cable stripping machines[14].

Table 3-15: Comparison between mechanical and manual separation process[14].

Type of processing	**Advantages**	**Disadvantages**
Mechanical shredder	• High throughput (multiple tons/hour) • Cable dimension flexibility	• Need for high copper content • Always residual copper in plastic residue
Manual/basic wire stripper	• High purity both copper and plastic	• Low output (10-15 kg/hour) • Change of settings per cable dimension • Economically barely viable

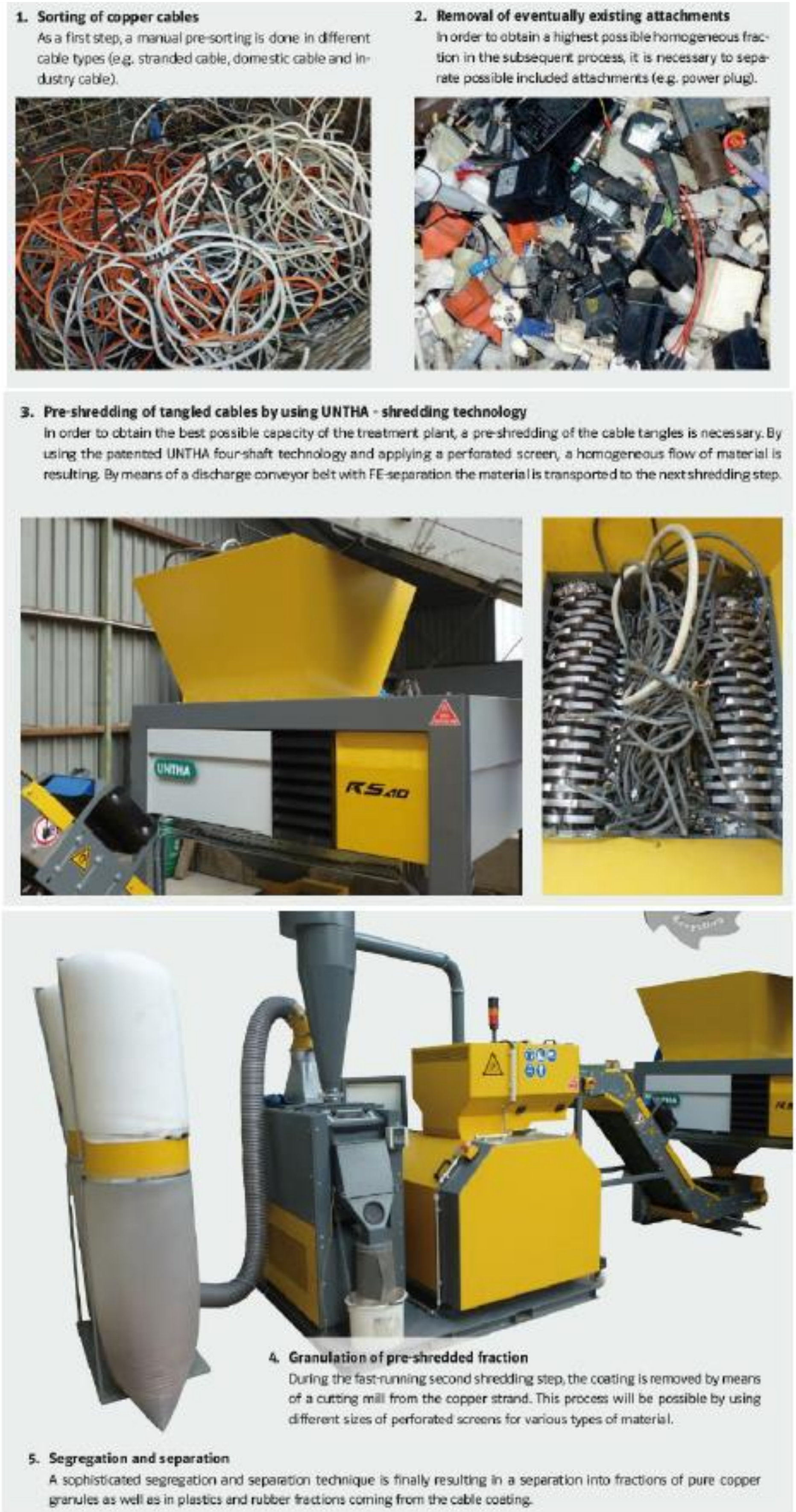


Figure 3-14: Detailed process flow of cable waste shredding[14].

Vinyloop – PVC recycling

In the study of the OVAM[14], another possibility for stripping power cables with softened PVC jacket and insulation was described, which is called Vinyloop®. Vinyloop is a chemical extraction technology developed by Solvay. The solvent-based technology recycles PVC and produces high-quality PVC. In Figure 3-15 the process is illustrated. In the beginning of the process, cable waste is reduced in size and brought into contact with the appropriate solvent, dissolving the softened PVC and separating the non-dissolved (non-ferrous) fraction. The solution, i.e. the solvent and dissolved PVC, is then submitted to a steam distillation process in order to recycle the solvent. At the end, the PVC compound fraction is dried and separated.

Figure 3-16 shows the amounts of recycled PVC since 2012. Recovered PVC material can technically be used for cable applications and coverings (e.g. flooring and tarpaulins), however this is currently not the case due to the price (Vinyloop is an expensive process) and colour.

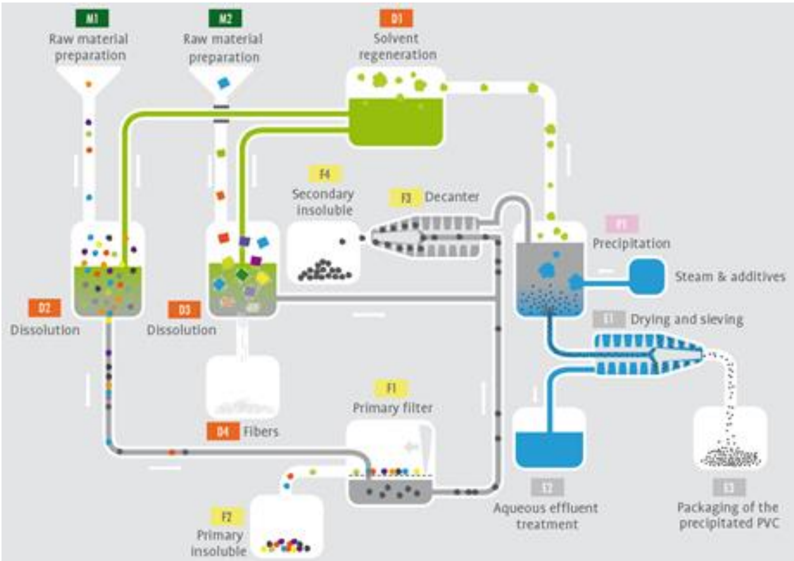


Figure 3-15: The Vinyloop® process.

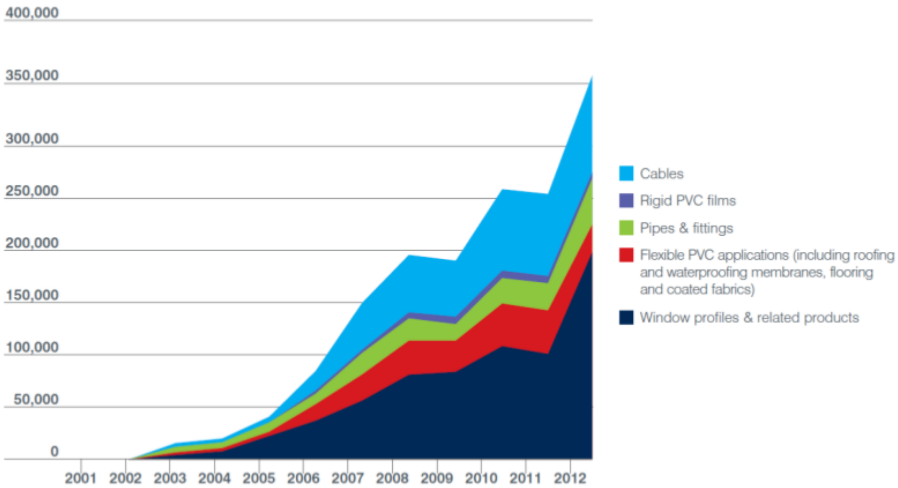


Figure 3-16: Amounts of recycled PVC (in tonnes) within the Vinyl 2010's and VinylPlus' frameworks.

Waste treatment XLPE

Recycling of cross-linked polyethelene (XLPE) is not possible yet due to its chemical cross-linked structure and the difficulty of thermo-plasticizing it. The three-dimensional lattice structure makes it impossible to melt it down again for moulding. As a result, almost all XLPE waste is currently incinerated for energy-recovery or disposed of in landfilles. There is no hope that an effective industrial-scale material recycling technology can be implemented.[14]

Use of recycled materials

According to the study by Flanders PlasticVision[14], there is no problem in using recycled copper and aluminium in new power cables provided it does not include any impurities. Cable material is rather specific due to its inherent properties, such as fire and mechanical properties. Using other sources of post-consumer waste is technically feasible, but will need very specific entry control and reprocessing.

EOL parameters

Note: This study deals with new power cables entering the market and that will have to be recycled when buildings are renovated (>20 years).

The following assumptions are made in this study:

- The End-of-Life (EOL) parameters are shown in Table 3-17. These match the default parameters of the EcoReport tool[15], except that 0% re-use for the non-ferro is used instead of 1%. Cables, removed from buildings, are not re-used. Repair & maintenance practice: not existing
- Second hand use: not existing

Table 3-16: Lifetime parameters per sector

Sector	Product life	Service life	Vacancy
Unit	Year	Year	%
Residential sector	64.00	60.80	5%
Services sector	25.00	23.75	5%
Industry sector	25.00	23.75	5%
Total sector (weighted)	41.60	39.52	5%

[15] EcoReport Tool version 3.06, VHK, MEErP 2011 METHODOLOGY PART 1 and PART 2

Table 3-17: End of life parameters

	Bulk Plastics	TecPlastics	Ferro	Non-ferro	Coating	Electronics	Misc. , excluding refrigant & Hg	refrigerant	Hg (mercury), **in mg/unit**	Extra	Auxiliaries
EoL mass fraction to re-use, in %	1%	1%	1%	0%	1%	1%	1%	1%	1%	1%	5%
EoL mass fraction to (materials) recycling, in %	29%	29%	94%	95%	94%	50%	64%	30%	39%	60%	30%
EoL mass fraction to (heat) recovery, in %	15%	15%		0%		0%	1%	0%	0%	0%	10%
EoL mass fraction to non-recov. incineration, in %	22%	22%		0%		30%	5%	5%	5%	10%	10%
EoL mass fraction to landfill/missing/fugitive, in %	33%	33%		5%		19%	29%	64%	55%	29%	45%

Note: according to Europacable[16], for plastics the recycling rate of the insulation and sheath are quite unpredictable as it depends on:

- the kind of materials that is used in the insulation (rubber is poorly recyclable, plastic is better recyclable, XLPE is technically recyclable but there are no existing channels today);
- the possibility to separate the plastics between them and from the rest of the cable (which may depend on the cable design and plastics mix);
- the countries, which may have different legislation and collection/treatment capabilities.

As a result it is thus not possible to provide generic information that could be used whatever the cable type for all European countries.

Europacable does not agree on the 95% recycling and 5% landfilling/missing/fugitive for non-ferro, regarding the actual sales price for recycled copper and aluminium. These assumptions might be too pessimistic. However they cannot provide any updated figures and therefore the above mentioned default values (Table 3-17) will be retained.

3.4 Local infrastructure (barriers and opportunities)

3.4.1 Opportunities

3.4.1.1 Effect on electrical installation and end-user

Reliability, availability and nature of the energy will not change when the resistance of the electrical system is changed.
Increasing the wiring size will also not influence the users of the buildings because the cables are typically hidden in walls or behind panels. Probably the users do not at all notice whether the wirings are slightly thicker or thinner.

[16] response of Europacable to second questionnaire http://www.erp4cables.net/sites/erp4cables.net/files/attachments/Europacable%20Comments%20Tasks%2012345f.pdf

3.4.1.2 Certification

Certification of the electric installation in buildings is in most of the EU countries required by legislation. Measures at the level of the electrical installation could therefore be verified and enforced at the certification stage. For instance in Belgium the electrical installations in houses need to be recertified when a house is sold. In the industrial and services sector in Belgium the local regulation specifies that recertification of the electrical installation by a certification authority has to be performed every 5 years.

3.4.1.3 Refurbishment occasions

Refurbishment occasions, like when houses are sold, provide an opportunity to stimulate the renovation of electrical installations.

In the residential sector financial incentive structures are one of the main instruments in redressing householders' unwillingness or inability to invest in energy efficiency by themselves. Financial incentives for energy efficiency measures, like wall insulation or new windows, may provide an opportunity for house owners to renew the electrical installation. Additional financial incentives for renewal of electrical installation may stimulate house owners to renew the electrical installation.

3.4.2 Barriers

3.4.2.1 Lock-in effect into existing installations

As illustrated in Figure 3-9 the cable can be placed direct in masonry or wooden wall, in conduits, cable ducts, on cable ladder, on brackets, on trays, in building voids, in a channel in the floor and so on. This installation method can create a kind of lock-in effect. In some of the methods the cables cannot be easily replaced unless a thorough renovation is done, for instance when the cables are placed direct in the masonry, making it more costly.

In the residential sector installers will choose more often methods of installation (lower cost) for which the cables are more difficult to replace. In the industry and services sector it often part of the requirements of the electrical installation that the cables have to be placed in ducts, conduits or voids, and are therefore easier to be replaced.

3.4.2.2 Implication on material use

Strategies like S+x or 2S will result for the same system in a larger use of material for the conductor and the insulation.

The relative increase in conductor material can be calculated with Formula 3.10.

$$relative\ conductor\ volume\ increase = \frac{V_{s+x} - V_s}{V_s} = \frac{r_{s+x}^2 - r_s^2}{r_s^2} \qquad \text{(formula 3.10)}$$

Where:

$V = (r^2)\pi L$

r = radius of conductor section

L = length of the cable
S and S+x indicate the associated CSA strategy

The additional need of material may have following consequences:

- Additional material use means additional mining and treatment of the raw material, with extra CO_2 emission;
- An effect on the material price. Future commodity prices, however, cannot be predicted. The amount of extra material needed will be determined by the design option and applied scenario.

Also a strategy like dual wiring would mean significant increase in material use.

Insulation/sheath/inner coverings and filler material increase:

The relative increase in insulation/sheat/inner coverings and filler material can be calculated with Formula 3.11 when cylindrical. For the inner coverings and filler material, when unknown, a ratio factor equal to the insulation/sheath material increase may be used. In case of a dual wire strategy the used material volume doubles.

$$relative\ insulation\ volume\ increase = \frac{V_{S+x} - V_S}{V_S} \qquad \text{(formula 3.11)}$$

Where:

$V = (r_o^2 - r_i^2)\pi L$
r_o = outer radius of insulation cylinder
r_i = inner radius of insulation cylinder = radius of conductor section
L = length of the cable
S and S+x indicate the associated CSA strategy

Conclusion:
The relative increase of conductor and insulation material for an S+x strategy can be calculated with formula 3.10 and formula 3.11 respectively. In case of a dual wire strategy the used conductor and insulation material volume doubles (=100% increase).

3.4.2.3 Handling and space requirements

Strategies like dual wiring and S+x strategies requires more space for the wiring in the building. A higher cable volume could exclude any possible renewal due to lack of space. Wires with larger sizes have also larger bending curves and are more difficult to handle.

3.4.2.4 Cost implications

Strategies like dual wiring and S+x strategies will increase the cost of:

- Cable per circuit,
- Cable transportation,
- Cable installation if more time is needed,
- Electrical installation equipment. Any modification of cables size may require a modification of the other equipment such as socket-outlet and other accessories in the electrical installation.

- building infrastructure. Apart from the space, use of higher cross-section will induce a non-negligible cost increase of the installation due to building infrastructure.

3.4.2.5 Economic product life (=actual time to disposal)

Lifetime is a crucial component of the life cycle cost (LCC) calculation. Power cables are durable and have long working lives.

The following materials[17] (Table 3-18) with lifetime figures for a wide range of products was developed for the US National Association of Home Builders (NAHB) Economics Department based on a survey of manufacturers, trade associations and product researchers.

Table 3-18: Lifetime of wiring according NAHB

Electrical	Life in years
Copper wiring, copper plated, copper clad aluminum, and bare copper	100+
Armored cable (BX)	Lifetime
Conduit	Lifetime

Source: Jesse Aronstein, Engineering Consultant

International Association of Certified Home Inspectors (NACHI)[18] and NAHB charts agree that copper wiring can last 100 years or more. But the real life expectancy of your wiring is not in the copper. It's dependent on the wiring's insulation, and that lifetime can vary widely.

The modern formula for thermoplastic NM-B type wiring dates from 1984, when the insulation's heat resistance was increased. The best guess is that it will provide over 100 years of service.

Therefore, it can be concluded that the economic product lifetime of wiring in modern electrical installations is not determined by the technical lifetime of wiring. Power cables are part of the electrical installation and are in general replaced when the complete electrical installation is renovated. An electrical installation will be partially or completely renewed when the building environment served by the electrical installation is changed or gets a new function. Also when new machinery or appliances are added to the installation it might be necessary to replace or upgrade part of the electrical installation. Therefore it's safe to conclude that the lifetime of electrical wiring is determined by the lifetime of the system of which the wiring is a component, thus the electrical installation.

[17] http://www.oldhouseweb.com/how-to-advice/life-expectancy.shtml

[18] http://www.improvementcenter.com/electrical/home-electrical-system-how-long-can-it-last.html

The PEP ecopassport®[19] is an environmental declaration program for electric, electronic and HVAC industries. Some Product Category Rules (PCR) have been developed, in accordance with ISO 14025[20], to carry out life cycle assessments of electrical, electronic and HVAC products in a transparent manner. Some specific rules have been developed for cables and wires and some lifetime of products are used as standard hypothesis and are provided in Annex 1 of PSR-0001-ed1-EN-2012 01 10 (Products Specific Rules for Wires, cables and accessories)[21]. The PEP ecopassport program considers an average lifetime of 30 years for energy cables in residential / tertiary building applications and industrial buildings (see Table 3-19). Those hypotheses have been agreed among cable manufacturers through the French cable Association (Sycabel)[27].

Table 3-19: Lifetime of cables and wires according their application[21]

AREAS APPLICATIONS	Applications	Lifetime (years)
INFRASTRUCTURES	Energy distribution networks	40
	Railway networks	30
	Telecom networks (fixed and mobile phones)	20
INDUSTRIAL APPLICATIONS	Oil, gas and petrochemicals	30
	Handling	10
	Automation	5
	Nuclear	40
	Wind turbines	20
	Photovoltaic power plants	10
	Airports	20
ONBOARD SYSTEMS	Civil aeronautics	15
	Shipbuilding and marine	30
	Rolling stock	30
	Automotives (Cars and trucks)	10
BUILDING	Residential/tertiary/industrial	30
	Data centers	10
	LAN : residential	10
	LAN: tertiary	10
	LAN: industrial (factories, warehouses)	10

The JRC report "Development of European Ecolabel and Green Public Procurement for Office buildings - Economical and market analysis"[22] of 2011 provides information on building stocks, renovation rate, construction, building age, etc. In section 4.2.1 "Assumed working life of products and systems", it mentions different sources for the working life of construction product and resulting tables (see Table 3-20, Table 3-21, Table 3-22, and Table 3-22).

[19] http://www.pep-ecopassport.org

[20] Environmental labels and declarations - Type III environmental declarations - Principles and procedures

[21] http://www.pep-ecopassport.org/documents/PSR0001-ed1-FR-20120110-Fils%20Câbles%20et%20Materiels%20de%20Raccordement-.pdf

[22] http://susproc.jrc.ec.europa.eu/buildings/docs/market%20and%20economic%20analysis.pdf

Table 3-20: Assumed working life of construction products[23]

Assumed working life of works (years)		Working life of construction products to be assumed in ETAGs, ETAs and HENs (years)		
Category	Years	Category		
		Repairable or easy replaceable	Repairable or replaceable with some more efforts	Lifelong[2]
Short	10	10[1]	10	10
Medium	25	10[1]	25	25
Normal	50	10[1]	25	50
Long	100	10[1]	25	100

[1] In exceptional and justified cases, e.g. for certain repair products, a working life of 3 to 6 years may be envisaged (when agreed by EOTA TB or CEN respectively).
[2] When not repairable or replaceable "easily" or "with some more efforts".

Table 3-21: Minimum design life of components[24]

Design life of building	Inaccessible or structural components	Components where replacement is expensive or difficult	Major replaceable components	Building services
Unlimited	Unlimited	100	40	25
150	150	100	40	25
100	100	100	40	25
60	60	60	40	25
25	25	25	25	25
15	15	15	15	15
10	10	10	10	10

Table 3-22: Design working life of components[25]

Design working life (years)	Examples
10	Temporary structures
10- 25	Replaceable structural parts
15- 30	Agricultural and similar structures
50	Building structures and other common structures
100	Monumental buildings, bridges, other structures

[23] European Organisation for Technical Approvals (EOTA) (1999). Assumption of working life of construction products in Guidelines for European Technical Approval, European Technical Approvals and Harmonized Standards. Guidance Document 002.
[24] ISO 15686-1
[25] European Commission (2002). EN 1990. Eurocode: Basis of structural design.

Table 3-23: Lifetime of cables and wires according their application

Design working life (years)	Examples
1-3	Information technology
5	Interior partition
10	Electrical systems
25	Mechanical systems
50	Skin (exterior)
100	Structure

Taking into account the variation amongst sources this study proposes the following lifetime values for power cables:

- Product life[26]: the product life is equal to the number of years between product purchased and product discarded. The product life is not necessarily the same as the product service life, e.g. because the product can be stocked before disposal. In case of power cables the product life is assumed equal to the life time of the building. Buildings have a not-in-service time part (vacancy) before getting into service, refurbished or discarded. During the not-in-service period the power cables do not transport energy and have thus no losses. The product life parameter is listed per sector in Table 3-24.
  Some of the stakeholders remarked that an average building lifetime between renovations of 8 years (12.4%, see Task 2) for the services and industrial sector is rather short. Europacable experts mentioned lifetimes of 40 to 50 years for cables in the services and industrial sector[27].
  Taking into account the variation amongst sources a short, long and reference cable product lifetime is provided in Table 3-24 per sector. The high and low values for the product lifetime will be applied in the sensitivity analysis in Task 6 and Task 7.

Table 3-24: Cable product lifetime

	short product life		Reference		long product life	
Sector	Replace-ment rate	Product life	Replace-ment rate	Product life	Replace-ment rate	Product life
Unit	%	year	%	year	%	year
Residential sector	2.10%	40	1.18%	64	0.80%	84
Services sector	7.08%	13	3.20%	25	1.70%	40
Industry sector	7.08%	12	2.80%	25	1.37%	40

- Product service life[26]: the product service life is the period in years that the product is in use and operational. The product service life parameter is listed per sector Table 3-24. The product service life of power cables is calculated with following formula:

$$Product\ service\ life = Product\ life - not\_in\_service\_time \quad \text{(formula 3.12)}$$

[26] Definition according VHK, MEErP 2011 METHODOLOGY PART 1.
[27] Europacable paper as response to the secondary questionnaire http://www.erp4cables.net/sites/erp4cables.net/files/attachments/Europacable%20Comments%20Tasks%2012345f.pdf

Where
- not_in_service_time = Product life * building_vacancy_factor
- building_vacancy_factor is assumed to be 5%

Conclusion:
The economic product lifetime therefore is determined by the refurbishment rate of the building. This refurbishment rate is related to the function type of the building (see Task 2).

3.4.3 Installers and certifiers of electrical installations

Potential affected:
- Electrical installation engineering companies
- Installers
- Certifiers

Designing taking energy efficiency and economy into account might require installers to invest in extra training, and design tools. These design tools have to be adapted by software development companies.

Installation time and related cost may increase due to extra wiring or more difficult handling of cables with larger sizes.

Installing extra cables or cables with a larger size will have no implications on the required know-how of the installer. Installers in the non-residential sector are used to handle large cable sizes.

Depending on the policy certifiers may have to include extra procedures in the certification process to verify the electrical installation.

3.4.4 Physical environment

As discussed in Task 1 the losses in electrical installations can be reduced by increasing the cable section or by reducing the load per circuit, having additional circuits for the same amount of load.

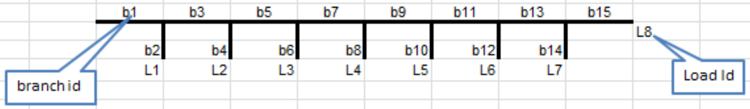
The building construction and electric installation will be affected by:
- thicker cables are less flexible and need more volume/space for installation
- thicker cables need larger ducts and tubing
- the connectors for thicker cables may be different and larger
- having more circuits will increase the space requirements for the distribution boards
- having more circuits will increase the space requirements for the cables (ducts)

ANNEX 3-A

The tables in this section illustrate the calculation of the Kd factor for a load branch length factor of respectively 10%, 50%, 100% and 200%. The load branch length factor is a factor to reduce the ratio between the even (b2, b4, etc.) and odd (b1, b3, etc.) branches. A factor of 100% means that the branches all have the same length. A factor lower than 100% means that the even branches are shorter than the odd branches. A factor more than 100% means that the even branches are longer than the odd branches. For instance for a load branch factor of 200% the odd branches are getting very small, so the topology of the circuit is moving towards a star point topology where every node has a dedicated branch towards the begin point of the circuit (circuit breaker). The used lengths for the branches are shown in each table.

Table 3-25: Kd factors: load branch length factor equal to 10%

CSA circuit	2,5	mm²
Cable resistivity per m	0,00672	Ω/m
Number of relevant cores	2	
I_{max} (circuit breaker)	16	A
Voltage	230	V
Pmax	3680	W
Circuit (total cable) length	30	m
Circuit loss at Imax	103,2192	W
Load branch length factor	10%	%



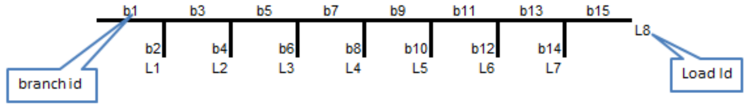
Number of branches with loa	1		2		3		4		5		6		7		8	
Load Id	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A
1	3680	16	1840	8	1226,67	5,33333	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
2	0	0	1840	8	1226,67	5,33333	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
3	0	0	0	0	1226,67	5,33333	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
4	0	0	0	0	0	0	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
5	0	0	0	0	0	0	0	0	736	3,2	613,333	2,66667	525,714	2,28571	460	2
6	0	0	0	0	0	0	0	0	0	0	613,333	2,66667	525,714	2,28571	460	2
7	0	0	0	0	0	0	0	0	0	0	0	0	525,714	2,28571	460	2
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	460	2

Branch id	1 Current A	1 Length m	1 loss (R.I²) W	2 Current A	2 Length m	2 loss (R.I²) W	3 Current A	3 Length m	3 loss (R.I²) W	4 Current A	4 Length m	4 loss (R.I²) W
1	16,00	30,00	103,22	16,00	14,50	49,89	16,00	9,60	33,03	16,00	7,18	24,70
2	0,00	0,00	0,00	8,00	1,00	0,86	5,33	0,60	0,23	4,00	0,43	0,09
3	0,00	0,00	0,00	8,00	14,50	12,47	10,67	9,60	14,68	12,00	7,18	13,89
4	0,00	0,00	0,00	0,00	0,00	0,00	5,33	0,60	0,23	4,00	0,43	0,09
5	0,00	0,00	0,00	0,00	0,00	0,00	5,33	9,60	3,67	8,00	7,18	6,17
6	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,00	0,43	0,09
7	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,00	7,18	1,54
8	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
9	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
12	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Total		30,00	103,22		30,00	63,22		30,00	51,84		30,00	46,59
Kd			1,00			0,61			0,50			0,45

Branch id	5 Current A	5 Length m	5 loss (R.I²) W	6 Current A	6 Length m	6 loss (R.I²) W	7 Current A	7 Length m	7 loss (R.I²) W	8 Current A	8 Length m	8 loss (R.I²) W
1	16,00	5,73	19,73	16,00	4,77	16,42	16,00	4,09	14,07	16,00	3,58	12,30
2	3,20	0,33	0,05	2,67	0,27	0,03	2,29	0,23	0,02	2,00	0,20	0,01
3	12,80	5,73	12,62	13,33	4,77	11,40	13,71	4,09	10,33	14,00	3,58	9,42
4	3,20	0,33	0,05	2,67	0,27	0,03	2,29	0,23	0,02	2,00	0,20	0,01
5	9,60	5,73	7,10	10,67	4,77	7,30	11,43	4,09	7,18	12,00	3,58	6,92
6	3,20	0,33	0,05	2,67	0,27	0,03	2,29	0,23	0,02	2,00	0,20	0,01
7	6,40	5,73	3,16	8,00	4,77	4,11	9,14	4,09	4,59	10,00	3,58	4,80
8	3,20	0,33	0,05	2,67	0,27	0,03	2,29	0,23	0,02	2,00	0,20	0,01
9	3,20	5,73	0,79	5,33	4,77	1,82	6,86	4,09	2,58	8,00	3,58	3,08
10	0,00	0,00	0,00	2,67	0,27	0,03	2,29	0,23	0,02	2,00	0,20	0,01
11	0,00	0,00	0,00	2,67	4,77	0,46	4,57	4,09	1,15	6,00	3,58	1,73
12	0,00	0,00	0,00	0,00	0,00	0,00	2,29	0,23	0,02	2,00	0,20	0,01
13	0,00	0,00	0,00	0,00	0,00	0,00	2,29	4,09	0,29	4,00	3,58	0,77
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00	0,20	0,01
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00	3,58	0,19
Total		30,00	43,58		30,00	41,64		30,00	40,28		30,00	39,28
Kd			0,42			0,40			0,39			0,38

Table 3-26: Kd factors: load branch length factor equal to 50%

CSA circuit	2,5	mm²
Cable resistivity per m	0,00672	Ω/m
Number of relevant cores	2	
I_{max} (circuit breaker)	16	A
Voltage	230	V
Pmax	3680	W
Circuit (total cable) length	30	m
Circuit loss at Imax	103,2192	W
Load branch length factor	50%	%

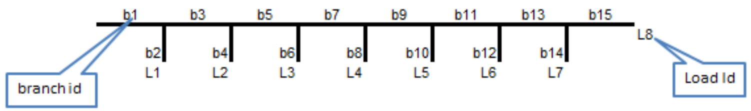


Number of branches with loa	1		2		3		4		5		6		7		8	
Load Id	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A
1	3680	16	1840	8	1226,67	5,33333	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
2	0	0	1840	8	1226,67	5,33333	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
3	0	0	0	0	1226,67	5,33333	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
4	0	0	0	0	0	0	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
5	0	0	0	0	0	0	0	0	736	3,2	613,333	2,66667	525,714	2,28571	460	2
6	0	0	0	0	0	0	0	0	0	0	613,333	2,66667	525,714	2,28571	460	2
7	0	0	0	0	0	0	0	0	0	0	0	0	525,714	2,28571	460	2
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	460	2

Branch id	Current A	Length m	loss (R.I²) W	Current A	Length m	loss (R.I²) W	Current A	Length m	loss (R.I²) W	Current A	Length m	loss (R.I²) W	Current A	Length m	loss (R.I²) W	Current A	Length m	loss (R.I²) W	Current A	Length m	loss (R.I²) W	Current A	Length m	loss (R.I²) W
1	16,00	30,00	103,22	16,00	12,50	43,01	16,00	8,00	27,53	16,00	5,89	20,28	16,00	4,67	16,06	16,00	3,86	13,29	16,00	3,30	11,34	16,00	2,88	9,89
2	0,00	0,00	0,00	8,00	5,00	4,30	5,33	3,00	1,15	4,00	2,14	0,46	3,20	1,67	0,23	2,67	1,36	0,13	2,29	1,15	0,08	2,00	1,00	0,05
3	0,00	0,00	0,00	8,00	12,50	10,75	10,67	8,00	12,23	12,00	5,89	11,40	12,80	4,67	10,28	13,33	3,86	9,23	13,71	3,30	8,33	14,00	2,88	7,57
4	0,00	0,00	0,00	0,00	0,00	0,00	5,33	3,00	1,15	4,00	2,14	0,46	3,20	1,67	0,23	2,67	1,36	0,13	2,29	1,15	0,08	2,00	1,00	0,05
5	0,00	0,00	0,00	0,00	0,00	0,00	5,33	8,00	3,06	8,00	5,89	5,07	9,60	4,67	5,78	10,67	3,86	5,91	11,43	3,30	5,79	12,00	2,88	5,56
6	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,00	2,14	0,46	3,20	1,67	0,23	2,67	1,36	0,13	2,29	1,15	0,08	2,00	1,00	0,05
7	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,00	5,89	1,27	6,40	4,67	2,57	8,00	3,86	3,32	9,14	3,30	3,70	10,00	2,88	3,86
8	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	3,20	1,67	0,23	2,67	1,36	0,13	2,29	1,15	0,08	2,00	1,00	0,05
9	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	3,20	4,67	0,64	5,33	3,86	1,48	6,86	3,30	2,08	8,00	2,88	2,47
10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,67	1,36	0,13	2,29	1,15	0,08	2,00	1,00	0,05
11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,67	3,86	0,37	4,57	3,30	0,93	6,00	2,88	1,39
12	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,29	1,15	0,08	2,00	1,00	0,05
13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,29	3,30	0,23	4,00	2,88	0,62
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00	1,00	0,05
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00	2,88	0,15
Total		30,00	103,22		30,00	58,06		30,00	45,11		30,00	39,40		30,00	36,24		30,00	34,25		30,00	32,89		30,00	31,91
Kd			1,00			0,56			0,44			0,38			0,35			0,33			0,32			0,31

Table 3-27: Kd factors: load branch length factor equal to 100%

CSA circuit	2,5	mm²
Cable resistivity per m	0,00672	Ω/m
Number of relevant cores	2	
I_{max} (circuit breaker)	16	A
Voltage	230	V
Pmax	3680	W
Circuit (total cable) length	30	m
Circuit loss at Imax	103,2192	W
Load branch length factor	100%	%



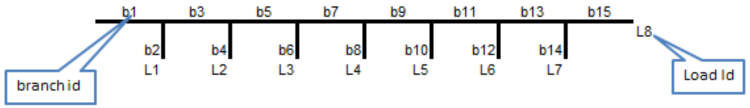
Number of branches with loa	1		2		3		4		5		6		7		8	
Load Id	Power usage	Current	Power usage	Current	Power usage	Current	Power usage	Current	Power usage	Current	Power usage	Current	Power usage	Current	Power usage	Current
	W	A	W	A	W	A	W	A	W	A	W	A	W	A	W	A
1	3680	16	1840	8	1226,67	5,33333	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
2	0	0	1840	8	1226,67	5,33333	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
3	0	0	0	0	1226,67	5,33333	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
4	0	0	0	0	0	0	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
5	0	0	0	0	0	0	0	0	736	3,2	613,333	2,66667	525,714	2,28571	460	2
6	0	0	0	0	0	0	0	0	0	0	613,333	2,66667	525,714	2,28571	460	2
7	0	0	0	0	0	0	0	0	0	0	0	0	525,714	2,28571	460	2
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	460	2

Branch id	Current (1)	Length (1)	loss (R.I²) (1)	Current (2)	Length (2)	loss (R.I²) (2)	Current (3)	Length (3)	loss (R.I²) (3)	Current (4)	Length (4)	loss (R.I²) (4)
	A	m	W	A	m	W	A	m	W	A	m	W
1	16,00	30,00	103,22	16,00	10,00	34,41	16,00	6,00	20,64	16,00	4,29	14,75
2	0,00	0,00	0,00	8,00	10,00	8,60	5,33	6,00	2,29	4,00	4,29	0,92
3	0,00	0,00	0,00	8,00	10,00	8,60	10,67	6,00	9,18	12,00	4,29	8,29
4	0,00	0,00	0,00	0,00	0,00	0,00	5,33	6,00	2,29	4,00	4,29	0,92
5	0,00	0,00	0,00	0,00	0,00	0,00	5,33	6,00	2,29	8,00	4,29	3,69
6	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,00	4,29	0,92
7	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,00	4,29	0,92
8	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
9	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
12	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Total		30,00	103,22		30,00	51,61		30,00	36,70		30,00	30,41
Kd			1,00			0,50			0,36			0,29

Branch id	Current (5)	Length (5)	loss (R.I²) (5)	Current (6)	Length (6)	loss (R.I²) (6)	Current (7)	Length (7)	loss (R.I²) (7)	Current (8)	Length (8)	loss (R.I²) (8)
	A	m	W	A	m	W	A	m	W	A	m	W
1	16,00	3,33	11,47	16,00	2,73	9,38	16,00	2,31	7,94	16,00	2,00	6,88
2	3,20	3,33	0,46	2,67	2,73	0,26	2,29	2,31	0,16	2,00	2,00	0,11
3	12,80	3,33	7,34	13,33	2,73	6,52	13,71	2,31	5,83	14,00	2,00	5,27
4	3,20	3,33	0,46	2,67	2,73	0,26	2,29	2,31	0,16	2,00	2,00	0,11
5	9,60	3,33	4,13	10,67	2,73	4,17	11,43	2,31	4,05	12,00	2,00	3,87
6	3,20	3,33	0,46	2,67	2,73	0,26	2,29	2,31	0,16	2,00	2,00	0,11
7	6,40	3,33	1,84	8,00	2,73	2,35	9,14	2,31	2,59	10,00	2,00	2,69
8	3,20	3,33	0,46	2,67	2,73	0,26	2,29	2,31	0,16	2,00	2,00	0,11
9	3,20	3,33	0,46	5,33	2,73	1,04	6,86	2,31	1,46	8,00	2,00	1,72
10	0,00	0,00	0,00	2,67	2,73	0,26	2,29	2,31	0,16	2,00	2,00	0,11
11	0,00	0,00	0,00	2,67	2,73	0,26	4,57	2,31	0,65	6,00	2,00	0,97
12	0,00	0,00	0,00	0,00	0,00	0,00	2,29	2,31	0,16	2,00	2,00	0,11
13	0,00	0,00	0,00	0,00	0,00	0,00	2,29	2,31	0,16	4,00	2,00	0,43
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00	2,00	0,11
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00	2,00	0,11
Total		30,00	27,07		30,00	25,02		30,00	23,66		30,00	22,69
Kd			0,26			0,24			0,23			0,22

Table 3-28: Kd factors: load branch length factor equal to 200%

CSA circuit	2,5	mm²
Cable resistivity per m	0,00672	Ω/m
Number of relevant cores	2	
I_{max} (circuit breaker)	16	A
Voltage	230	V
Pmax	3680	W
Circuit (total cable) length	30	m
Circuit loss at Imax	103,2192	W
Load branch length factor	200%	%



Number of branches with loa	1		2		3		4		5		6		7		8	
Load Id	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A	Power usage W	Current A
1	3680	16	1840	8	1226,67	5,33333	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
2	0	0	1840	8	1226,67	5,33333	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
3	0	0	0	0	1226,67	5,33333	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
4	0	0	0	0	0	0	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
5	0	0	0	0	0	0	0	0	736	3,2	613,333	2,66667	525,714	2,28571	460	2
6	0	0	0	0	0	0	0	0	0	0	613,333	2,66667	525,714	2,28571	460	2
7	0	0	0	0	0	0	0	0	0	0	0	0	525,714	2,28571	460	2
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	460	2

Branch id	1: Current A	1: Length m	1: loss (R.I²) W	2: Current A	2: Length m	2: loss (R.I²) W	3: Current A	3: Length m	3: loss (R.I²) W	4: Current A	4: Length m	4: loss (R.I²) W
1	16,00	30,00	103,22	16,00	5,00	17,20	16,00	2,00	6,88	16,00	1,07	3,69
2	0,00	0,00	0,00	8,00	20,00	17,20	5,33	12,00	4,59	4,00	8,57	1,84
3	0,00	0,00	0,00	8,00	5,00	4,30	10,67	2,00	3,06	12,00	1,07	2,07
4	0,00	0,00	0,00	0,00	0,00	0,00	5,33	12,00	4,59	4,00	8,57	1,84
5	0,00	0,00	0,00	0,00	0,00	0,00	5,33	2,00	0,76	8,00	1,07	0,92
6	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,00	8,57	1,84
7	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,00	1,07	0,23
8	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
9	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
12	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Total		30,00	103,22		30,00	38,71		30,00	19,88		30,00	12,44
Kd			1,00			0,38			0,19			0,12

Branch id	5: Current A	5: Length m	5: loss (R.I²) W	6: Current A	6: Length m	6: loss (R.I²) W	7: Current A	7: Length m	7: loss (R.I²) W	8: Current A	8: Length m	8: loss (R.I²) W
1	16,00	0,67	2,29	16,00	0,45	1,56	16,00	0,33	1,13	16,00	0,25	0,86
2	3,20	6,67	0,92	2,67	5,45	0,52	2,29	4,62	0,32	2,00	4,00	0,22
3	12,80	0,67	1,47	13,33	0,45	1,09	13,71	0,33	0,83	14,00	0,25	0,66
4	3,20	6,67	0,92	2,67	5,45	0,52	2,29	4,62	0,32	2,00	4,00	0,22
5	9,60	0,67	0,83	10,67	0,45	0,70	11,43	0,33	0,58	12,00	0,25	0,48
6	3,20	6,67	0,92	2,67	5,45	0,52	2,29	4,62	0,32	2,00	4,00	0,22
7	6,40	0,67	0,37	8,00	0,45	0,39	9,14	0,33	0,37	10,00	0,25	0,34
8	3,20	6,67	0,92	2,67	5,45	0,52	2,29	4,62	0,32	2,00	4,00	0,22
9	3,20	0,67	0,09	5,33	0,45	0,17	6,86	0,33	0,21	8,00	0,25	0,22
10	0,00	0,00	0,00	2,67	5,45	0,52	2,29	4,62	0,32	2,00	4,00	0,22
11	0,00	0,00	0,00	2,67	0,45	0,04	4,57	0,33	0,09	6,00	0,25	0,12
12	0,00	0,00	0,00	0,00	0,00	0,00	2,29	4,62	0,32	2,00	4,00	0,22
13	0,00	0,00	0,00	0,00	0,00	0,00	2,29	0,33	0,02	4,00	0,25	0,05
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00	4,00	0,22
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00	0,25	0,01
Total		30,00	8,72		30,00	6,56		30,00	5,19		30,00	4,25
Kd			0,08			0,06			0,05			0,04